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Dual Axis Solar Tracker: Trends, Influence & Impact

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Dual-Axis Solar Tracker

By

Alazone Smith

MET 489 ABC
CWU-MET 2019

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Abstract

The global energy crisis and continued supporting evidence of global climate change have begun to shift the world economies towards solutions that solve both challenges. Solar power has become one of the most recognizable and popularized renewable energy methods to date. In comparison to other photovoltaic systems, this project demonstrates the performance advantages of a dual-axis solar tracker. It also addressing its viability on a non-commercial scale. The objective was to improve upon previous solar tracker projects at Central Washington University by adding another axis to the system. This system implements both an actuator and a stepper motor to examine the advantages of using different drivers. Initially, the theoretical design and construction plan of the device was developed. Sketches and drawings were created with engineering analysis and supporting research for the best possible results. The manufacturing phase encompassed project management, risk mitigation and materializing the theoretical design. Materials, logistics, and human resources are all processed during this period, in accordance with the proposed budget and schedule, to ensure the project came to fruition. Based on the deliverables set out by the design requirements, the project provided largely successful results. The entire project was developed under budget, on schedule, with both axes functioning as intended, and under the weight limits. The photovoltaic was able to maintain a perpendicular relationship with sunlight within 3% tolerance. The energy collected was approximately 38.9% more than the PV cell without the tracking system.

INTRODUCTION

1.a) Description

Through an age of unprecedented technological advancement, humanity has developed a gargantuan reliance on energy. Generating energy has become one of society's most prioritized challenges. In attempts to improve energy availability, the solar cell was invented. A solar cell is a device that converts the energy of light directly into electricity, by using photovoltaic effect.

b) Motivation

The motivation from the project came from the social relevance of solar energy. Amid a global energy crisis, instruments such as solar panels need to be used to their highest potential. Therefore, there is a substantial need for methods that can optimize their energy collection. One of these methods is the use of solar tracking systems. These devices have become more utilized in the past decade, leading to several types of tracking systems. In fact, a previous student at CWU, completed a solar tracker in the past. The hope for this project is to produce a fully operation, dual-axes, active solar tracker, that will improve upon the capabilities of the previous model.

c) Function Statement

A device is needed that will vertical and horizontally adjust a solar panel, so it may maintain a perpendicular relationship with direct sunlight. In turn, it will generate more electricity than a standard, fixed solar panel.

d) Design Requirements

The device must meet the following constraints:

- Construction of device shall not exceed the **\$250** in pricing
- Panel needs to maintain a **perpendicular (90 degree) angle** with direct sunlight, with a **1-3% tolerance**.
- **Azimuthal axis** needs to have a range of **180 degrees of rotation** from any position
- **Altitudinal axis** provides an angle of declination of at least **45 degrees**
- Start to finish **construction** should take no more than **250 working hours**.
- Absorb **25% more energy** than a fixed solar panel.
 - Approx. **100 watts**
- The fully constructed device will weigh no more than **100 lbs**.

e) Engineering Merit

This project applies numerous engineering principles and concepts, many of which were learned through various courses in the MET program, from Central Washington University. Strength of materials, software coding, stress analysis, and potentially heat transfer will be the most utilized principles for this project.

f) Success Criteria

Success for this project can be considered as having fully operational adjustments from both axes. It must also be able to accurately maintain the perpendicular angle with the 1-3% tolerance. These will be considered the standards for success.

g) Scope of Efforts

The project will consist of four critical components. The solar panel is the foundation of the device which will be mounted and positioned above the base to improve durability and structure competence. The base will provide stability to all the other components. Between the base and the solar panel will be two drivers; a stepper motor and a linear actuator. Each driver will have control of an axis, either vertical or horizontal.

h) Benchmark

There are numerous solar trackers on the open market and several others developed through scholar work. This project will be in direct relation to the previous Solar Tracker developed by a CWU student in 2018.

i) Project Success

True project success will be based on whether the device is able to sense and adjust to the perpendicular angle with a tolerance of 5-10% and absorb at least 10% more energy than the fixed solar panel.

DESIGN & ANALYSIS

2. a) Approach

The design for the solar tracker is to follow the sun's position by increments of time by azimuthal and altitudinal axes. In order to track the sun on the azimuthal axis, a stepper motor is used, while the altitudinal axis will be driven by a linear actuator. These are the most common forms used in tracking systems, commercial or otherwise.

b) Design Description

This tracking system is designed to operate for a 25W, 12VDC Arco M-25 PV. The general idea is that it will be able to track the sun up to 12 hours a day throughout the year, depending on the location and weather of the region. The project will consist of a multitude of materials, most are purchased through various vendors, while some will be manufactured. The manufactured portions will primarily consist of steel sheet metal, aluminum pipes, and some wood. These materials were chosen due to their strength regarding their uses, accessibility, and cost. The completed assembly should have a lower portion that is safe guarded by weather and fall hazards; this portion will consist of the motor system, the microcontroller, and battery. The open-ended portion will be the freely moving panel with framing and the actuator. The end result of this design is to maximize efficiency, in regard to power and costs.

c) Benchmark

There have been several previous solar tracking projects in the CWU MET department, both have been single-axis trackers using only a motor to for operations. This project is intended to improve upon the results of the previous project, with the intention of adding a linear actuator for the altitudinal axis. Linear actuators are very commonly applied to industrial and commercial solar trackers.

d) Performance Predictions

The completed construction of the tracking system is anticipated to weigh less than 100 lbs. It is anticipated to costs no more than \$250 for the purchase of all parts and the manufacturing. The power efficiency is still to be determined. Its areas will also be no larger than 2.5 ft.² and have a height no larger than 3 ft. Lastly, the solar tracker should collect 23% more energy than a fixed solar panel system and 8% more than a single axis system, with a tolerance angle within 3 degrees from perpendicular relation to sun.

e) Description of Analysis

The design for this project was conceived initially based on specifications of the PV panel acquired by CWU and the MET department. Beginning with the physical dimensions to establish a basis for construction of the mechanical system, working from top to bottom, and then using its electrical specifications as a basis for determining the power and current requirements for the electrical system. Some of the analysis established are used for the purposes of testing, and potential scenarios.

f) Scope of Testing and Evaluation

In relation to the stated requirement and performance prediction, the scope of testing and evaluation will focus intensely on some aspect and will not need to evaluate other factors as critically. For instance, the weight, cost, and structure will be evaluated by simple calculations or measurements. While on the other hand, on the tolerance of the axis' ranges are very important features that must be tested and evaluated more critically. The azimuthal axis must rotate at least 180 degrees, while the altitudinal axis must be able to maintain a degree that maximizes energy intake but not go below a certain angle, to avoid structural failure. The PV's theoretical power generation will be compared against the tested values to ensure the panel can maintain a perpendicular relation with the sun within 1-3 degrees of fall off.

g) Analysis

Appendix A1 shows the theoretical formulas that will be used to calculate ideal circumstances for energy collection. The analysis consists of calculations for angle of declination, elevation angle, and angle of incident. Each of these variables are critical in a dual-axis system for calculating energy collection. The resulting formulas will be used later for calculating energy loss vs. angle deviation and energy input.

The main objective of the dual-axis tracker is to follow the position of the sun for maximum energy efficiency. Given that the sun moves at 15 degrees per hour and assuming, the tracker would make position changes every .01 seconds, the change in angular velocity is calculated. The analysis can be found on Appendix A2, while the information can be referenced in Appendix B5.

Appendix A3 addresses the needed loading required to propel the PV and frame from 0 degrees (anticipated start position). Assuming the weight of the PV and frame combine for 16lbs, and the frame is pinned on one, a FBD and stress/moment diagram are used to find the required load at the connection point from the link to the panel. This information will be relevant to Appendix B6

Knowing that a motor will be used to drive the azimuthal axis, Appendix A4 shows the calculation of required torque for the motor. Using the Power equation, with the angular velocity from A2 and assuming the motor has a power rating of 1 HP. It was calculated that the required torque of the motor must be at least 190×10^3 ft-lbs. This information will be depicted in Appendix B7. It is also noted that this analysis is prone to modification based on motor selection and other variables.

Using the information from A4 and assuming the steel as the material of choice, A5 shows the calculation of the shaft diameter for the motor. The values appear to be much larger than anticipated, so this analysis may be changed or discarded in the final process, as the motor will most likely be selected based on other constraints, such as cost or power rating.

A6 shows the part of the calculations for the electrical system. Initially the PV's rated current is calculated to determine the minimum rating for the regulator. A standard regulator size is 5 Amperes, which satisfies the system requirements, so it was selected.

The second portion of the electrical system is carried out in A7. The overall power rating of the system is needed to determine how much power will be used and is needed to ensure the system can operate throughout the day. Using the information from the proposed motor, actuator, and PV, it was determined that the system will have a power rating of 270W/day. This is considering the lapse in usage, and peak sun hours. This information was used to select a 12VDC, 30Ah battery.

Understanding that there is a potential for snow fall in Ellensburg, A8 considers the loading that the system would need to overcome in case of snow. Information from weathersparks.com regarding snow in Ellensburg was used for the calculations of the PV while in operation and while in start position. When in operation it was calculated that snow could add an additional

Wind loading is also a common factor in Ellensburg, A9 addresses the standard loading at any time, while the system is in operation. The area of the surface is given as well as wind data from weathersparks.com as well. The average wind speed was recorded as 6.6 mph and the calculation uses as S.F. of 2 to account for extreme wind. Using the wind loading equation it was calculated that the system would undergo 1.022 lbs. of force.

A10 addresses the stagnation pressure that would be applied to the system. Using the same wind speed from the previous analysis and the assumption that the air pressure is 1.225 kg/m^3 .

A11 represents the deformation and stress that will apply to the central support shaft. Using the specifications from the drawing referenced in Appendix B2, the estimate of 25 lbs. load, and Aluminum 6061-T6 as the material. The deformation and direct tensile stress equations were used to determine a 0.041in deformation and 34 psi tensile stress. This will be noted Appendix B2 as well.

A12 addresses the starting position that is required for the actuator of the altitudinal axis. The analysis uses basic trigonometry and the Pythagorean Theorem to determine the max extension required to leave a 3" height from the bottom of the T-platform. The max extension length was calculated to be 11.6" and produce a 14.3 degree of declination. These values will be used for the programming of the device, and the analysis can be referenced on Appendix B9.

h) Device: Part, Shapes and Conformation

The visual representation of this design was developed based on the inspiration taken from various other solar tracker systems, both single-axis and dual-axis. The most notable points of emphasis may be the choice to incorporate both a motor system and an actuator. This decision was made based on the lack of other models that integrated both these methods in one device. The hope is that this feature will provide a milestone of research for future models attempting this strategy. Also minimizing the interference between the moving parts, while maximizing the protection for the electrical components was the reason for establishing a confined base and separating its interaction with the moving components.

i) Device Assembly and Attachments

All relevant parts and components are addressed in the Methods and Construction section (3.a). This sub-section lists each part that make up this system, it also addresses each relevant parts' related appendix, showing that individual parts specifications. A full representation of the mechanical system can be referenced in Appendix B6 and the electrical work flow can be reference on Appendix B5. In summary, this design will be completed from three sub-assemblies that make up the final product; the base, the top (moving components), and finally the electrical system. Once each subs-assembly is completed, they will make up the completed dual-axis solar tracker.

j) Tolerances, Kinematics, Ergonomics

Regarding tolerances, this project will focus on minimizing nonessential calculations, by applying standard sizes and tolerances at each stage of manufacturing. For example, the actuator will have a standard hole size, that will be used as the dimensions for the connector links' shaft, and that sizing will be reused for other components to limit amount of measurements to document. The anticipation is to keep most manufacture parts within +/- 0.010 tolerance and all angle tolerances within 3 degrees. Lastly, some values and tolerance will be adjusted during the process of construction based on changing values and unforeseen circumstances.

After acknowledging that this device will be tested outside, natural events play a large role in the performance of the system. The PV system will experience heat transfer (Appendix A15). The entire system could experience large amounts of snow loading (Appendix A8) or wind loading (Appendix A9). Evaluation of the system will have to address potential for falling, and failure of major moving components. Lastly, as the large PV and frame move about the azimuthal axis the weight should not shift and that is very important in ensuring there is no failure of the base.

Lastly, this device supports some of the most fundamental principles of ergonomics. Because this is a dual-axis solar tracker and it less mobile than a single-axis tracker, after it is placed there is little need to move the device. This allow the operated to remain in neutral position, while the device is in operation. Also, the moving components of the device are position at a height that is in-between the comfort/power zone (between the knee caps and top of torso). Lastly, the design established minimizes excessive motion and force.

k) Technical Risk Analysis, Failure Mode Analyses Safety Factors, Operation Limits

During development of this solar tracker design it is anticipated that there will be financial, resource, scheduling and technical aptitude risk.

Currently, there are no set funds for the construction of the project, so the largest cause for concern is not have enough fund to acquire all components, or potentially going over budget due to under planning. Prior to construction, all components will be double-checked for system compatibility and prices will be referenced from various resources to ensure best price. It will also be important to ensure the provided funds are sufficient for

complete the project, if the project is underfunded, components will be purchased on credit.

Secondly, have a very detailed manufacturing plan will be key to mitigating some of the other major risk. While it is anticipated that there will be no setbacks during construction, it's important to plan for the worst scenario. Having a high attention to detail while performing any manufacturing operation, while also having excess supplies prior to manufacturing will be the best methods for minimizing scheduling and resource conflicts. At any time, a part does not arrive on time or a setback occurs there will need to be changes to the schedule to ensure all components are completed on time, even if they cannot be established within the planned sequence.

Lastly, the electrical system will be largely constructed with the assistance of a peer with the EET expertise. This is critical to the success of the project, so it will be crucial to ensure a good working relationship and communication with the assistant. There will have to be constant evaluation of the completed work, while potentially keeping other assistants in mind in case of any unresolvable issues that could arise.

Most of the risk will be mitigated by incorporating extended delays into schedule, overestimate pricing of parts, and underestimating the work pace of all laborers. At any point that there is an issue that can't be solved, guidance will be sought from the advisors and the local community.

Methods and Construction

The project development has been undergone at Central Washington University. The components of the project have been designed and analyzed using the resources provided by individual research, instructor input, and other available resources through the MET department.

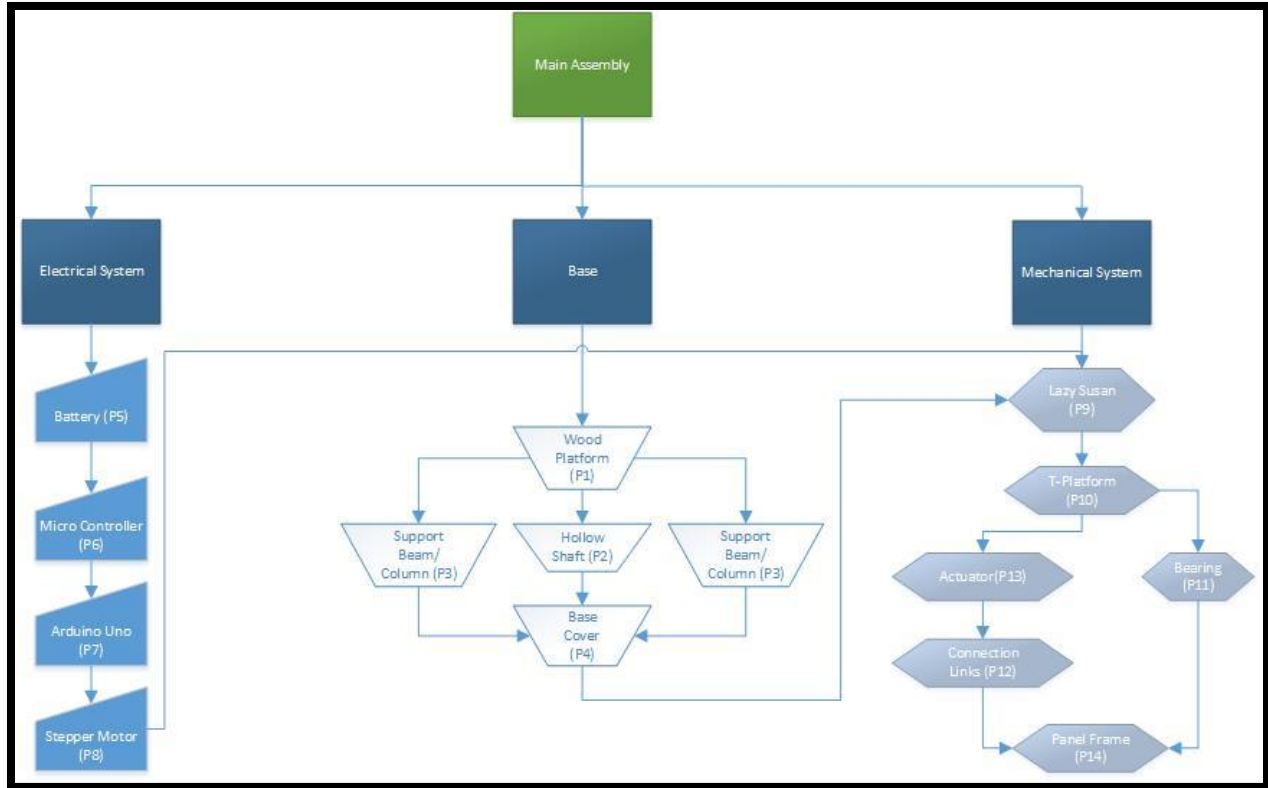
3.a) Description

The construction of the device should consist of 15 major components, this is not including variable materials such as wires, electrical components, and so on. Also, the reference for each necessary drawing is also provided below in the description of the part:

- Part 1 (P1): Wood Platform
- Part 2: Central Support Shaft (Appendix B2)
- Part 3: Support Beam/Columns (Appendix B3)
- Part 4: Base Cover (Appendix B7)
- Part 5: Battery
- Part 6: Microcontroller
- Part 7: Arduino Uno
- Part 8: Stepped Motor
- Part 9: “Lazy Susan” Bearing
- Part 10: T-Platform (Appendix B10)
- Part 11: Mount Bearing (Appendix B9)
- Part 12: 3 Connector Links (Appendix B8)
- Part 13: Linear Actuator
- Part 14 (P14): Panel Frame (Appendix B1)
- Part 15 (P15): Sensor Housing (Appendix B11)

b) Drawing Tree & Drawing ID's

Provided below is the drawing tree of the design. The components will be used to establish 3 sub-assemblies, leading up to the final construction. The drawing tree of this project can be Acknowledged on appendix B.7.



Initially, the base (Sub-Assembly 1) of the project will be starting point of construction to ensure stability and establish boundaries for later components. This will consist of a rectangular wood base (P1) which will be manufactured with mounting points. A hollow central support shaft (P2) and columns/walls (P3) will be the support for the sheet metal (P4) at the top of the base. This assembly will act as support for the moving parts above and as safety factor for the electrical system within in. The second sub-assembly will consist of the electrical system. The exact connections can be addressed on the work flow chart on appendix B5. The battery (P5), microcontroller (P6), Arduino uno (P7), and the stepper motor (P8) will all be encompassed within the base. A hole will be drilled through the top sheet metal for the shaft clearance and then the gear of the motor will be place within a “Lazy Susan” bearing (P9). The bearing will be the bridge between the moving components and the stationary base. A “T” shaped steel/aluminum platform (P10) will mounted to the top of the bearing and serve as the base of the actuator and frame set up. For the last sub-assembly, a wood frame (P14,) will be constructed around the panel to prevent damage from drilling, and act as a safety precaution in the event of actuator or link failure. At one end of the panel, the frame will be mounted to the platform using a manufactured bearing out of Aluminum T6-6061 (P11). The other end of the panel will be attached to two aluminum links (P12) which will serve as the connection from the actuator (P13), which sits on the platform as well. A sensor housing (P15) that will be 3-D printed will sit in the center of the panel frame on the highest side. For a full visual refer to appendix B6.

c) Parts List and Labels

Part Name	Identification Number	Description	Supplier
Wood Platform	P1	3'x2'x5/8" wood	CWU
Central Support Shaft	P2	Aluminum T6-6061 – Wire Housing	CWU
Support Beam/Columns	P3	Aluminum T6-6061	CWU
Base Cover	P4	Aluminum Sheet Metal	M-H building
Battery	P5	12VDC, 30 Ah	Apex Battery
Microcontroller	P6	Refer to Appendix C1	Amazon
Arduino Uno	P7	Provided by Department	CWU
Stepped Motor	P8	Refer to Appendix C1	DigiKey
“Lazy Susan” Bearing	P9	Refer to Appendix C1	WWExpress
T-Platform	P10	Aluminum Sheet metal	M-H Building
Mount Bearing	P11	Manufactured	
Connector Links	P12	Aluminum T6-6061	Ace Hardware
Linear Actuator	P13	Refer to Appendix C1	Amazon
Panel Frame	P14	Assembly of 3 wood pieces (documented in budget)	CWU
Sensor housing	P15	Use for photoresistors – ABS Plastic	CWU

d) Manufacturing Issues

It should be noted that all machining operations required for the development of this project will include the manual milling machine, drill press, table saw and lathe. Using the knowledge and skills gained from MET 255, majority of manufacturing will be performed in Hogue’s machine and wood shops. Potential complications that should be addressed during manufacturing and construction process:

There should be an emphasis on clearance will holes to ensure all parts can be assembled with ease. This is especially important for the connector links, bearings, and frame. These parts are within the moving parts space, if parts are unable to move freely it can compromise the data and energy conversion.

Ensuring alignment of all stationary parts is also a matter that should be addressed. The support beams, central shaft, and “Lazy Susan” Bearing each are in critical locations as they will play important roles in the systems structural integrity. These components must be positioned correctly because they help form the foundation. Also, poor placement could result in deformation of the base cover and/or cause a shift in the center of gravity, cause the top-heavy components to fall.

Outside of the structural development, this project requires a good deal of expertise from the EET department. The electrical system devised is the basic assembly of the components, however the equipment must be programmed to perform as intended. The

intent during construction is to acquire the expertise of a skilled programmer to establish the correct coding for this solar tracking system.

Manufacturing Progress Report:

Nearing the completion of the project (approx. one month away), the mechanical component of the project is moving along with large strides. Nearly all the wood components are completely manufactured. The upper components, such as frame, links, and mounts are nearing the assembly phase. The bottom of the project is primarily the base without the electrical components. Furthermore, the electrical components have been difficult to narrow down due to the wide variety of brands and specification, as well as compatibility with the Arduino Uno microcontroller. Close communication with Matt Burvee and Jeff Wilcox has been helpful in narrowing down the correct parts.

For the most part, each new acquisition or manufacturing operation, leads to new developments and modifications of other components. For instance, the particular cuts made on the available wood would require new calculations of the mounting points for the links. Also, with the actual diameter of the actuator bearing require resizing of the links; and so, on and so forth. In response to this development, proper measurements and analysis have been undergone multiple times prior to purchasing new parts or starting new manufacturing operations, in an effort to mitigate errors and more analytical work. The project remains on schedule and under budget, with continued help from the MET and EET faculty the project should be a success.

e) Assembly, Sub-assembly, Parts, Drawings

The information provided in this section will not only explain the detailed sequence of construction, but the sequence of acquisition for all the resources:

Description of process	Resources
1. Manufacture Base (Appendix B1, P1)	Wood
a. Saw to correct dimensions.	
b. Mill mounting points.	
2. Manufacture Support Beams/Columns (Appendix B3, P3)	Aluminum
a. Mill to specified length.	
b. Shape to ensure parallel contact points between base and cover.	
3. Manufacture Central Support Shaft (Appendix B2, P2)	Aluminum Shaft
a. Mill to specified length.	
b. Drill clearance for wires.	
4. Manufacture/Acquire Gear (TBD)	Aluminum
a. Mill gear to fit “Lazy Susan” bearing.	
5. Manufacture Base Cover (P4)	Sheet Metal
a. Drill hole for gear shaft.	
b. Drill clearance for screws.	
6. Sub-assembly 1 (Base)	
a. Mount Support Columns and Central Shaft to Base. (SA_11)	
b. Assemble Motor, Gear, and “Lazy Susan” Bearing. (SA_12)	
c. Secure SA_11 to SA_12 by screwing base cover to support columns.	

- d. Secure Motor to support shaft, use Zip-Tie.
7. Manufacture T-Platform (Appendix B10, P10) Sheet Metal
 - a. Mill excess material.
 - b. Shape boundaries on both ends.
8. Mount T-Platform to “Lazy Susan” (SA_21)
9. Secure Actuator to thin end of T-platform using Zip-Tie (SA_22) Actuator
10. Manufacture Mounting Bearings (Appendix B9, P11) Aluminum
 - a. Mill to specified dimensions
 - b. Mill shaft clearance
 - c. Drill screw clearance
11. Manufacture Connector Links (Appendix B8, P12) Aluminum Rods
 - a. Mill to specified length.
 - b. Drill shaft clearance
12. Manufacture Frame (Appendix B4, P14) Wood
 - a. Use Table saw to cut all pieces to correct dimensions
 - b. Mill shaft clearances
 - c. Drill clearance for PV wires and sensor wires
13. Assemble PV Frame (SA_23)
 - a. Nail frame together around PV panel
14. Manufacture Sensor Housing (Appendix B11, P15) ABS Plastic
 - a. 3D Print
15. Sub-assembly 2 (Top)
 - a. Mount Bearings to wide ends of Platform (SA_24)
 - b. Attach all shafts will links (SA_25)
 - c. Mount Sensor Housing with Sensors to PV Frame (SA_26)
16. Sub-assembly 3 (Electrical Systems)
 - a. Obtain assistance from EET Department (SA_31)
 - b. Assemble all components and construct (SA_32)
 Arduino Uno
 Battery
 Microcontroller
 Voltage Regulator
 Photoresistors
 - c. Program Arduino Uno (SA_33)
 - d. Test (SA_34)
17. Correct if anticipated results not obtained and modify any features as needed.

Testing Method

4.a) Introduction

The testing methods for the solar tracker will be based on the constraints set by the requirements and the performance predictions. As a recap, the requirements are listed below:

The device must meet the following constraints:

- Construction of device shall not exceed the **\$250** in pricing
- Panel needs to maintain a **perpendicular (90 degree) angle** with direct sunlight, with a **1-3% tolerance**.
- **Azimuthal axis** needs to have a range of **180 degrees of rotation** from any position
- **Altitudinal axis** provides an angle of declination of at least **45 degrees**
- Start to finish **construction** should take no more than **200 working hours**.
- Absorb **23% more energy** than a fixed solar panel.
 - Approx. **100 watts**
- The fully constructed device will weigh no more than **100 lbs**.

The most important constraints that relate to the performance of the device are related to the angle and tolerance of the axes, the system efficiency, and the dual-axes system compared to other systems. Each of these factors will be tested and evaluated critically, while the other constraints, such as weight, cost, and dimension will all generally be calculated by accumulation of the individual components and evaluated based on a pass-fail standard. The primary test will be evaluated based on their accuracy and precision in comparison to the performance prediction, and the comparison analysis. At this current point in the project it, a Fluke Multimeter is the primary tool that will need to be acquired prior to critical test.

The initial tests for the system's drivers can be referenced in Appendix I. These tests are the foundation of operation for the system.

b) Method/Approach

Provided below is a list of the performance prediction and serve as a reference to how test will be performed, considering not all these markers are relevant to the critical tests:

- Weigh less than 100 lbs.
- Costs no more than \$250
- The power efficiency is still to be determined.
- Its areas will also be no larger than 2.5 ft.² (from ground level)
- Height no larger than 3 ft.
- Collect 23% more energy than a fixed solar panel system
- With a tolerance angle within 3 degrees from perpendicular relation to sun.

Prior to the test of the fully operational system the driver components were tested. The methods can be referenced in Appendix I. The methods for the drivers how they were tested to determine if they would be operational for the full system. Once these tests were completed then the comparison tests described in the following paragraph could be undergone.

The largest milestone for success is ensuring the completed system produces more energy than the comparable systems. To establish these values, a full test shall be run of the system as designed, then compare against the same device but only using the horizontal axis, and finally compared again with the PV fixed. The current and voltage will be calculated from each test and analyzed to determine the performance of the device. To address the tolerancing of the angle, markers will be established at specific points on both axes. This will show whether the program moves both axes as intended and that the actuator and motor are performing correctly. Lastly, system efficiency will be tested by using the battery as a reference for how much energy is drained from it and how much it is charged after a full test.

c) Test Procedures

The in-depth test procedures for the actuator and the motor can be addressed in Appendix I. The procedure provides the step by step process for obtaining the data about the systems operational parameters.

Once, the device is fully operational there are 3 main tests to consider that this project may focus on, each sub-procedure will be explained below:

System Comparison:

For establishing the power generated by each system, initially the data will be obtained from the device when it operates as intended (Trial 1). A Multimeter will be used to record the data. Next, the system will be re-programmed to set the vertical axis to the maximum angle of incident, while the horizontal axis will continue to perform as intended (Trial 2). The data will be recorded then, a final test will be performed with the device re-programmed to a fixed position (Trial 3). All the data will be comprised in an excel spreadsheet and used to establish a critical analysis of the results.

Angle & Tolerance:

This testing will be performed during the initial operation of the device as intended. Markers will be placed on specific points on the horizontal and vertical axis to be referenced as milestones that the system should reach. For example, If the device should reach 45 degrees by 3 p.m. on the horizontal axis then that may be used as one of the markers. All data will be recorded by hand, and the error percentage will be calculated based on the actual position of the axes at the milestone times.

System Efficiency:

This test will be carried out by first initially, recording the voltage rating of the battery prior to testing and then once again at the end of the testing (Trial 1). The change in voltage will either reflect the efficiency of the system, based on how much energy is

redistributed back to the battery or how much energy was used to run the system. This can be severely affected based on the weather conditions of the test day, and that will be factored into heavily during this test.

A standard tape measurer has tolerance of 1/16th inch and this is will be reference if a tape measurer is required. The Fluke Multimeter is also considered as it generally has tolerances to the .005 voltage and current. The data for most of the test will be collected on paper and then later transferred to a Word and Excel document.

d) Deliverables

The structural parameters that will be evaluated are height base area, axis rotation in both planes. While the performance parameters will focus on the voltage and current outputs from the PV from different systems, and the power efficiency from the battery. This solar tracker system will be considered successful if it is structurally sound (Max weight of 100 lbs. and no more than 50lbs. above base), both axes are able to rotate to the full range of degrees stated, while allowing the panel to maintain a perpendicular relation with the sun with a 3-degree max tolerance.

The completed testing data can be referenced in Appendix G, while a detailed summary of the conclusion for the initial tests for the drivers of the system can be found in Appendix I.

Budget/Schedule/Project Management

5.a) Proposed Budget

The complete part list and proposed budget can be referenced in appendix C1 and D1, respectively. The information in both tables addresses the acquisition of all main components and estimated labor. Most parts that will be provided through a supplier were compared to other sources to ensure the best deal was being made.

Discuss part suppliers:

Many of the components will either be acquired through the MET department at CWU or through purchase from Amazon.com. There are also a variety of other suppliers that provided better quality materials or provided the same material but at a better price than Amazon. A large portion of the budget is dedicated to purchasing the Motor, Actuator, Battery and Labor. Some very low-cost parts were not factored into the budget as they will be variable components and the pricing should be factored in after construction. A \$20 budget can be assumed for this decision to omit these components. The purchasing or resource sequence can be referenced in section 3.e of this document.

Determine labor or outsourcing rates & estimate costs:

The assistance of an EET peer will be used in the development of the electrical system. A large majority of the engineering calculation should be established prior to programming, so it was estimated that the labor required should not exceed 3 hours. Also, using standard minimum wage rates in Ellensburg (\$11/hr), this was used to determine the cost of labor.

Labor:

They will all be performed by the individual researcher, not including the assistance from the EET department.

Estimate total project cost:

Based on the total budget which estimates the project to cost \$216.30, and accounting for the variable materials estimated at \$20. The total project cost should be estimated at \$236.30, which is acceptable as the completed project is not to exceed \$250.00.

Funding source(s):

Funding for this project has three potential sources; The MET department's funding committee, the researcher's personal funds, and funding provided through grants from CWU.

Manufacturing Progress Report:

Up-to-date the project remains on track to complete under budget. The proposed cost of the entire project came to \$216.30 and with one month left prior to completion, the project's

expenditures are approximately \$202.06. Components already purchased are as follows: an actuator, all wood components, fasteners, adhesives, measurement tools, Lazy Susan bearing, and aluminum dowels. The most significant factor, resulting in under budget results, maybe the contributions from the wood shop and the EET department, as they can provide most of the wood for the structure, as well as batteries and other electrical components.

Due to changes in the design, many parts have had changes in terms of suppliers and models, however with attention to detail; sourcing of parts has been cheaper while maintaining quality. For instance, the Lazy Susan bearing, sensor housing, and actuator were all acquired for less money than previously priced. Also, the EET assistant has forgone pay to use the experience and project in addition to their degree requirements.

All but two parts currently acquired have been personally inspected prior to use to ensure it was the correct part. The actuator and lazy Susan bearing arrived on time, as expected. In the following weeks. The remaining parts to be acquired will be many of the electrical components including; Motor, gear, linear shaft bearing (pillow block), motor drivers, LDR sensor, and a regulator. Most of these components can be ordered together in a bulk haul, which should limit the wait time. The sourcing will be done by Matt Burvee and any parts unable to obtain will be purchased individually. Also, this will be the last remaining orders, which is expected to cost no more than \$100. Leaving the project to complete under budget.

Testing Progress Report:

After completing test two it was clear there needed to be modifications to the motor to ensure the device was fully functional. The options were to purchase a motor with a higher torque or the same motor with a planetary gear system. The decision was to purchase the planetary gear system motor as it required less energy to operate while still providing the same results. A NEMA 17 stepper motor with a 100:1 gear ratio was purchased through Amazon along with new mounting brackets. The cost of these modifications came to a total of approximately \$59.50. The exact cost is currently unknown as the products were purchased through the MET Technician (Matt Burvee) who is in possession of the receipts at this time. These necessary changes made the horizontal axis operational and brought the grand total of the project to \$246.41. Considering the design requirement was to have a budget under \$250, this still makes the project successful from a financial standpoint.

b.) Proposed schedule

The entire design, construct, and test sequence is set between the start of fall quarter 2018 and is to be completed by the end of spring quarter 2019, during the MET 489ABC courses. The provisional schedule provided in Appendix E1, is used to organize and plan the entire process of the project, at all points.

High Level Gantt chart:

The provisional schedule was created using an excel file and is a simple quasi-Gantt chart. As stated, before it can be referenced in Appendix E1; it notes the description of

each individual task, regardless of commitment, the expected durations, completions, and important milestones.

Deliverables, milestones:

The project has a total of 8 milestones. The initial milestone that is to be completed during the fall quarter is the Draft Proposal. During the winter quarter 5 of the milestones will be reached in the development of the solar tracker, in order; Analyses Mod, Document Mods, Final Proposal, Part Construction, and Device Construct. The final two milestones that will be reached are Device Evaluation, then end with 489 Deliverables.

Total project time:

The total time estimated for the competition of this solar tracker project is expected to be under the requirement of max. 250 hours, with 234.8 hours.

Manufacturing Progress Report:

The initial manufacturing plans scheduled were constructed to assemble the device with a down-up methodology. However, it was advised to begin construction with a top-down approach. This decision required many changes to the schedule, to reflect the timing changes for part acquisition. Also, as the project progressed it was clear that multiple adjustments were needed for the drawings and assembly. More time has been allocated to maintaining documentation, planning and implementation of the project as new developments arise. The assistance of Matt Burvee and his assistant have been helpful for maintaining progress through less-productive periods of time, such as awaiting parts, troubleshooting or even locating resources. The project continues to maintain momentum towards completion and with close monitoring and continuous revisions, it is expected to be constructed on schedule.

After a detailed analysis of the up-to-date schedule as the project construction comes to an end, the work proposed and accomplished can be compared. Initially, the project was meant to start by building the device from the bottom (base) up, however with an emphasis to complete the moving components system, within the first two weeks, this method was reverse (working top to bottom). The complete schedule can be viewed in Appendix D and up to this moment in time the project was estimated to need 172.3 hours of work. The project required 179 hours of work. It also acknowledges there is an estimated 83 hours more of work required for the testing phase in 489C. Since, the project required an abundance of changes throughout the construction period there was little time to implement changes to documentation as the project progressed. Therefore, many of the decisions made were device based on the principal engineer's best judgement, backed by either intense research or the advice of peers and mentors.

Testing Progress Report:

Initially the testing phase was meant to focus primarily on testing the autonomous system compared to a single axis system and a fixed system. However, with the electrical system not fully programmed at the time of construction completion, the first test addressed the drivers' functionality. The actuator worked as intended as did not a more time to the project, but the motor was not operational. This set the project back about one week and require significantly more time to make more calculations and modifications to the device. Since the horizontal was

not operational but still movable the power efficiency test was conducted with the azimuthal axis being re-positioned manually. After a new motor was sourced and remounted, the device finally had both axes operational. The total working hours put into this project at this point is 248 hours. This places the project just 2 hours under the total expected working hours. The only steps left are to retest the programs established with the fully autonomous system which should not take any longer than 2 hours. Therefore, it can be concluded that in regard to schedule, the project was a success.

c.) Project Management

Through detailed planning, project management helps to mitigate risk that could arise further into the project while also improving the overall quality of the completed product.

Human Resources:

The principal engineer will provide expertise in mechanical design, 3D drafting, and all other forms of course work skill obtained while at CWU. The principal engineer's resume is shown in Appendix J1. A select group of faculty from the MET department Technology in Central Washington University will provide expertise in analysis development, machining, and general support, to ensure the project succeeds.

Other Resources:

This project will require a substantial amount of physical resources, a list is compiled below shows the primary resources that will be used:

- Hogue Computer Labs (Rooms: 118 & 119)
- Hogue Wood Shop & Machine Shop
- Computer equipped with MS office
- The financial support from sponsorship, and/or community

Discussion

6.a) MET 489A

At this point in the projects progression there have been a multitude of changes from the first initial week of work. The project began with very little focus and over time narrowed down in scope. This project began basing analysis off the provided PV panel and the online resources researched to understand the concepts that were implemented in this project. It can be stated that more time was potentially done trying to understand the concept than to apply them. In total, the design of this project went through 3 major changes.

The first design had the horizontal axis powered by a single support shaft and it used 2 motors for the whole system, this design would have required far too much torque for the project to be economically viable. In hope to reduce the require torque and improve structural stability, the 2nd design implemented a linear actuator and a motor. This design was very close to the final draft however there were many complications with clearance for both axes to perform to full extent. The higher moving components also used truss, which provided to security for the more

expensive electrical components. The final design which is the main design referenced in this document ended by adding separation between the moving parts and electrical system. The project also switches the dc motor to a stepper motor for the ease of programming. Lastly, the final draft implements a lazy Susan bearing to improve the ease of movement of the heavier moving components and established enough clearances, for both axes to move freely.

b) MET 489B

One week until the due date of the project and there have been a multitude of unforeseen obstacles. As stated earlier in this document, manufacturing of this project has led to constant re-designing and logistical issues. The early stages comprised primarily of part acquisition, adjustments to documentation, and lastly developing more intel. Through much research and networking, more information on the design and electrical system were collected. With the assistance of various peers and advisors, the project has remaining progressive. While the project has moved forward, it has done so with sacrifice. The most recent issue in manufacturing was the shaping of the T-Platform. With the principal engineer's lack of welding knowledge, there had to be design changes that added weight to the project. While adding weight to the project improved the chances of failure, however it was the best decision to make as alternatives manufacturing methods would have been more time costly to the project. Not only has manufacturing seen drawbacks but the electrical system has not fully been acquired until the week prior to completion. The electrical system is vital to the assembly of the project. The most critical change to the project would be the addition of a thrust bearing which will be used to mount the motor directly to the sheet metal. The connection to the sheet metal to the motor was a concept that was not quite understood initially but through much research it should provide better stability to the system and a more convent assembly.

As the construction period ends it should be acknowledged that this project took on a very different shape than initially planned. There were a multitude of changes and modifications made not only to the device but very connected document. There have been numerous more analysis needed, weekly adjustments to the schedule to account for drawbacks and periods of abundant progress, and the materials acquisition list (Appendix C.2) may be like the proposed budget but provides many more components that were needed to complete the device.

c) MET 489C

Now with construction complete, the focus shifts towards testing and adjustments.

Test One:

The first initial test proposed focused on the system comparisons between the device in question and that of a single-axis and fixed system. However, the project has only been completed mechanically up-to-date. Therefore, this portion of the project is a combination of electrical system development and testing simultaneously. The first test developed for the current state of the device ensures the functionality of the motor drivers and the operating constraints for programming as well as the literal operations of the system. The test data for this first test can be found on the data sheet provided in Appendix I. Test 1 was a trial and error method of using

various programs to understand which coding formats worked best for the system. The actuator testing used the change in position of the actuator and of the frame's relative position to determine the maximum and minimum angle of declination. Also, it established the operating speed which were important for documentation and for a more efficient program. The results were very similar to the calculated value except for the max actuation length, about 1 inch short. The DC motor was unable to be tested during this time. The current reasoning is that there is too much load on the motor shaft adapter. The bolts that fixed the frame had also been stripped and without the proper tools to remove them, and reduce the load, the motor will have to be tested later. However, the information is valuable to the project moving forward as it highlights room for improvement. The motor testing will address any areas of interference between wires or the motion of the axis as well as the time to complete revolutions.

Test Two:

The motor test was meant to observe the interference frequency, speed, and time during one full revolution from the start position. However, the motor test has been deemed a failure due to several discrepancies. Initial test of the motor before installation to the system worked well but were unsuccessful when used in application. The motor would not move the system with all the components assembled and as a result, to better understand the issue, components were removed incrementally to see how much weight it could rotate. However, once all components except the platform it's mounted to were removed, the motor still would not rotate. The motor created a loud clicking sound that was determined to be either a slipping within the shaft adapter or within the motor itself. From the information gathered there was either an issue with how tightly fastened the adapter was to the motor shaft or that the radial load was too much to overcome. Since the motor was operational with all programs outside of application, the issue must be mechanical. Further calculation is required to determine if a stronger motor is needed also. Following this test, the system will need to be further disassembled to determine the threshold force that can be applied to the adapter. Considering the technical difficulty to reassemble once it has been taken apart, other methods for solving the issue will be considered as well.

Test Three:

Following test two, the power efficiency of the system using the solar panel was still the main focus. Since the motor was not operational, the azimuthal axis was repositioned manually with the assistance of a digital compass and sun tracking data for improved precision and accuracy. The actuator was operational which made repositioning the altitudinal axis feasible. Also, during the same time period an additional solar panel was set up at a fixed position to establish comparable data between both types of systems. The data was compiled over a 5-hour period and provided successful results for the dual-axis tracking system which can be referenced in Appendix G. An in-depth summary of the analysis can be referenced in Appendix I. Also, after an analysis of the device was conducted it was concluded that there was a miscalculation of the torque required to turn the azimuthal axis. Therefore, in an effort to ensure the device became operational a new torque calculation was determined using a stepper motor program with constraints similar to this system (index table). From there a new motor with the appropriate specifications was located. All other necessary components for mounting were purchased and the necessary modifications will be made prior to the final presentation of the device.

Conclusion

Analysis Phase: This Dual-axis Solar Tracker System has been conceived, analyzed and designed to meet the function requirements presented. All necessary parts and resources have been specified, sourced and budgeted for acquisition. After firm analysis and review it can be said that the device in question is ready to be manufactured.

This project meets all the requirements for a successful senior project, including:

1. Meeting set size, financial, and effort constraints.
2. Developed analytical merit as well as expertise in the solar tracking industry
3. Established a great foundation for research

More information will be provided in the future to reflect the outcomes of the construction and evaluation portions of the project.

Construction Phase: Based on the requirements initially set forth in the design and analysis section of this document, there are many reasons to consider this device a success:

First, the project was set to be priced under \$250 and with a complete acquisition list that places the project at \$246.41, this objective was completed with \$3.59 to spare. The project was \$30.11 over budget from the proposed \$216.30 during the analysis phase.

While the overall the work hours up to completion was 179 hours, 6.7 hours over the proposed schedule at this point, the project can still be deemed a success in these terms. The proposed hours were made on little background knowledge of the required manufacturing process and with lack of experience as a project manager. With that in mind, the difference in hours of work can be considered negligible as it is approximately a 3.7% margin of error. Also, the device was constructed on time even though it required more hours.

From first-hand experience of lifting the device for presentation purposes, it is most likely that the device does not weight more than 100 lbs. This statement will be later confirmed in the testing phase of this project. However, considering the principal engineer is also employee in construction (manual labor) and must lift weights up to 200 lbs. on a regular basis, there is prior experience with estimating weight to back this claim.

While the electrical system is not now completely wired and operational, through mechanical testing during construction, both axes have full ranges of motion as intended. The azimuthal axis swivels 360 degrees and the altitudinal axis extends from a 55 degree of declination to approximately 32 degrees of declination, which is suitable parameters for solar test in Ellensburg.

Testing Phase:

After conducting several tests and making a few modifications to the device, it can be said that the project was a success. The completed analysis of the data can be referenced in Appendix G which will show that the dual-axis tracking system outperformed the fixed system by 38.9% which is 13.9% higher than the anticipated 25% increase. An in-depth analysis of validation for these results can be referenced in Appendix L under the Testing & Results section. Also, both the actuator and motor have been adjusted so that they are both fully autonomous. For an end project comparison, all the design requirements and results are listed below:

Design Requirement: Result (Goal)

Energy Output: 102.4W (100W)	Success / Fail
Energy Increase, Over fixed system: 38.9% (25%)	Success / Fail
Tolerance: +/- 3% (1-3%)	Success / Fail
Total working hours: 250 (250)	Success / Fail
Total Costs: 246.41 (\$250)	Success / Fail
Max Weight: 100lbs (66.4 lbs.)	Success / Fail

Acknowledgements

Time should be taken to recognize the efforts and support of all the persons below, much appreciation should be given in advance;

- Mathew Burvee
- Prof. Charles Pringle (MET)
- Dr. Craig Johnson (MET)
- Prof. John Choi (MET)
- Denis Valsenko, EET 19'
- Prof. Jeff Wilcox (EET)
- Prof. Peter Zencak (EET)
- Prof. Ted Bramble (IET)
- Rowdy Sanford (EET)
- All colleagues and peers of the Principal Engineer

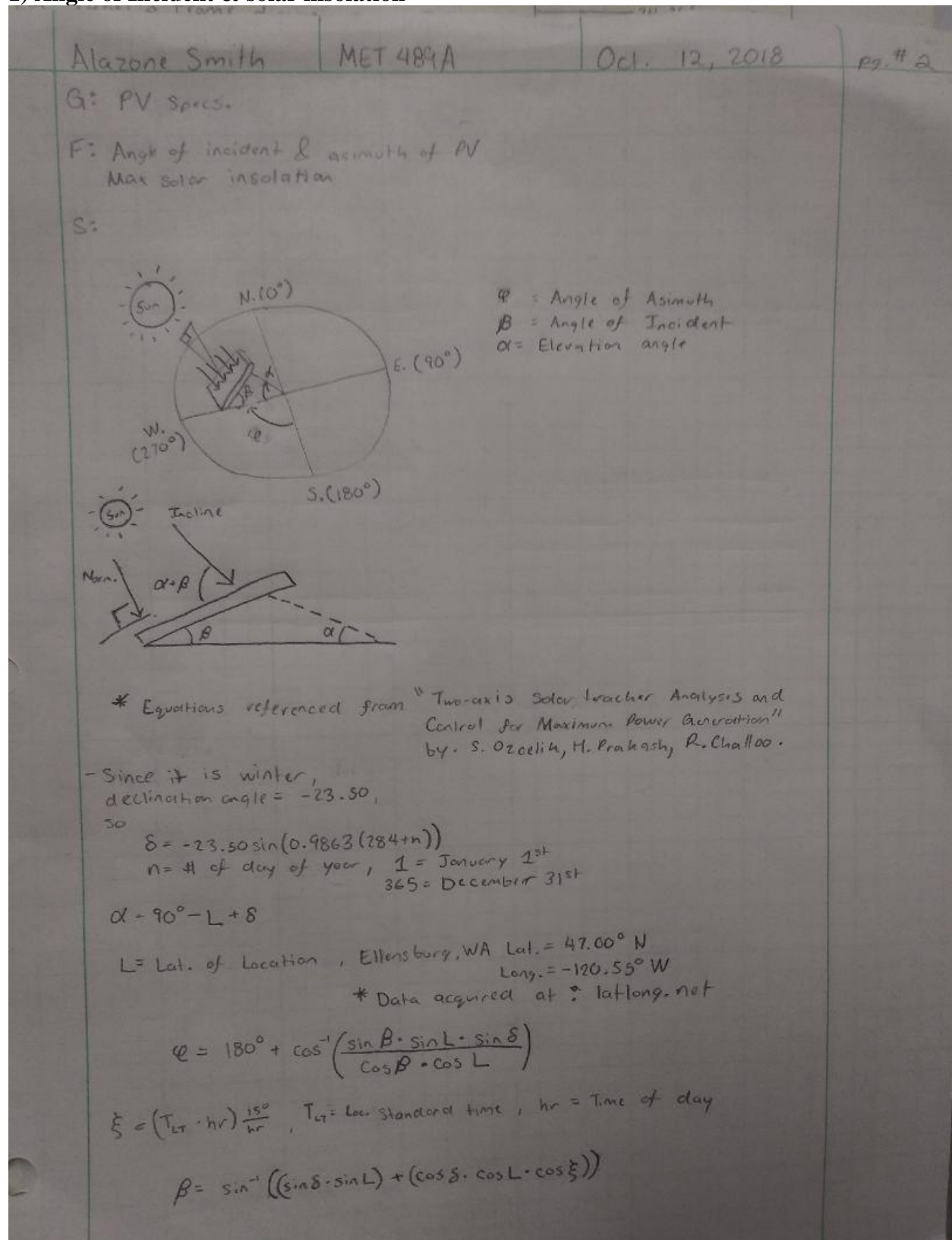
Thank you to Central Washington University for all support and resources it provides. Without the resources available in CWU, this project could not be plausible.

Reference

- Statics Textbook
- Technical Dynamics Textbook
- Machine Elements in Mechanical Design Textbook
- Matweb.com
- Weatherspaks.com
- Calculator.net
- All provided suppliers

Appendix A

1) Angle of Incident & solar insolation



2) Degrees of rotation

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G: $\Delta\theta_{\text{sun}}/\text{hr} = 15^\circ$ * math central. Oregon Co
Assume $\Delta t = 0.0255$

F: Vertical $\Delta\omega$

* horizontal position will adjust based on tracker placement

S:
$$\Delta\omega = \frac{\left(\frac{15^\circ}{\text{hr}}\right) \cdot \left(\frac{1 \text{ hr}}{3,600 \text{ sec}}\right) \cdot \left(\frac{2\pi \text{ rad}}{360^\circ}\right)}{\Delta t}$$

$$\Delta\omega = \frac{0.00727 \text{ rad}}{0.0255}$$

$$\Delta\omega = 0.0029 \text{ rad/s}$$

3) Actuator Force on Frame

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G: Panel & Frame dimensions
Assume weight on bottom board is ≈ 16 lbs.

F: F_R @ A, (Force required to lift Panel)
& M_B

M: ① FBD
② Equilibrium

S: $16 \text{ lb} / 24.25 \text{ in} \approx 0.66 \text{ lb/in}$

$F_R + B_y = 16 \text{ lbs.}$

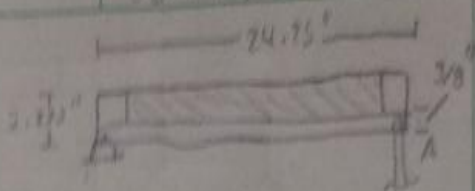
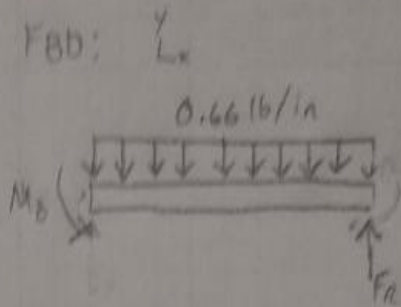
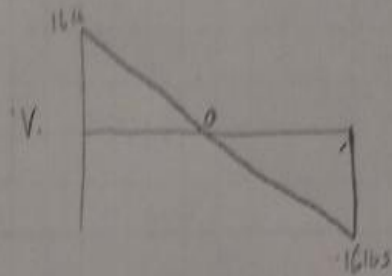
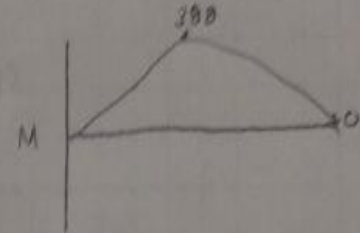
$\sum F_x, B_x = 0$

$\sum M_B = 0; \quad 16 \text{ lbs.} \cdot F_R = 0$
 $F_R = 16 \text{ lbs.}$

$F_R + B_y = 16 \text{ lbs.}, B_y = 0$

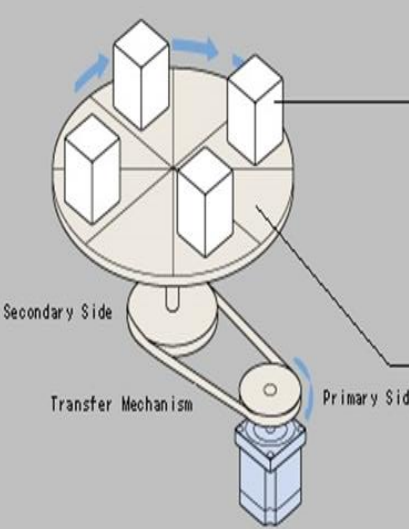
$M_B = 16 \cdot 24.25$
 $M_B = 388 \text{ lb-in}$

Actuator must provide at least 16 lbs. of force

4) Motor Torque

File(F) Others(O)



Secondary Side

Transfer Mechanism

Primary Side

Transfer Mechanism

☒ Not equipped

☐ Equipped

* The gear reduction ratio of Oriental Motor's Geared Motor does not need to input.

Load

☒ Equipped

☐ Not equipped

Table

☐ Density

☒ Mass

Moment of Inertia of a Load Calculation

Moment of Inertia per Piece: $2281.889 \times 10^{-4} \text{ kg}\cdot\text{m}^2$

Mass: 4.54 kg

Quantity:

Distance: mm

Diameter: mm

Thickness: mm

Material:

Density: $\times 10^3 \text{ kg/m}^3$

Thickness: kg

Other Moment of Inertia: $7583.211 \times 10^{-4} \text{ kg}\cdot\text{m}^2$

Load Torque Calculation

Transfer Mechanism Reduction Ratio

Load Torque (total): 5.692 N·m

Moment of Load Inertia (total): $14809.160 \times 10^{-4} \text{ kg}\cdot\text{m}^2$

* Load torque and moment of load inertia are values converted for the primary side.

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5) Shaft Diameter

DESIGN OF SHAFTS					
Application: <i>Design Example 12-1, Drive for a Blower System</i>					
<i>Diameter D_3 - To right of point B - Bending and torsion</i>					
This design aid computes the minimum acceptable diameter for shafts using Equation 12-24 for shafts subjected to steady torsion and/or rotating bending.					
Equation 12-16 is used when only vertical shear stress is present.					
Input Data: <i>(Insert values in italics)</i>					
Shaft material specification: <i>AISI 1020 CR Steel</i>					
Tensile strength:	$s_u =$	60,900	psi		
Yield strength:	$s_y =$	50,800	psi		
Basic endurance strength:	$s_n =$	24,000	psi	From Figure 5-11	
Size factor:	$C_s =$	0.75		From Figure 5-12	
Reliability factor:	$C_R =$	0.81		From Table 5-3	
Modified endurance strength:	$s_n' =$	14,580	psi	Computed	
Stress concentration factor:	$K_t =$	2.5		Shoulder fillet - actual	
Design factor:	$N =$	2		Nominal $N = 3$	
Shaft Loading Data: Bending and Torsion					
Bending moment components:	$M_x =$	0	lb-in	$M_y =$	0 lb-in
Combined bending moment:	$M =$		lb-in	Computed	
Torque:	$T =$	0	lb-in		
Minimum shaft diameter:	$D =$	0.00	in	Computed from Eq. 12-24	
		0.00	in	If ring groove	
Shaft Loading Data: Vertical Shearing Force Only					
Shearing force components:	$V_x =$	-22	lb	$V_y =$	77 lb
Combined shearing force:	$V =$	80	lb	Computed	
Minimum shaft diameter:	$D =$	0.284	in	Computed from Eq. 12-16	

6) Electrical Systems – Current & Regulator

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Gi: PV, $V = 12V$ DC
 $P = 25W$
Short Circuit Current = 1.3A * offgridgeek.com, Measured

F: • PV, I
• Solar Regulator
• System loading
• Battery

M: ① I, calculated current ② Regulator
③ Power rating of all components
④ Battery

S: ① I

$P = V \times I$, $I = P/V$
 $I = 25W/12V$, $I = 2.083 A$

Regulator, $I_R > (I_{PV} = 2.083 A)$
 $I_R = 2 \times 2.08 A$
 $I_R = 4.16 A$ ∴ 5 AMP regulator
* Jameco.com (Part # 192284)

7) Electrical Systems – Power Rating & Battery

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② System Power Rating

List components:

- DC Motor (Assume) 12DV, 3A, $P_m = 36W$ ✓
- Linear actuator (Sovik, Amazon) 12V DC, 2A ✓
↳ $P_a = I \cdot V$; $\Rightarrow (12V \cdot 2A) = 24W$

Operations expected: Dec - March,
Use 4.5 hrs. / avg. usage

$$- \text{Total load} = (36W \cdot 4.5 \text{ hr/day}) + (24W \cdot 4.5 \text{ hr/day})$$

$$T_L = 270 \text{ wh/day}$$

③ Battery

$$\text{Req. Ah} = \frac{(T_L / 12V)}{0.7 \cdot 1.1}$$

- "0.7", Min. power level

- "1.1", account for 90% battery efficiency

$$\text{Req. Ah} = \frac{(270 \text{ wh/day} / 12V)}{0.7 \cdot 1.1}$$

$$\text{Req. Ah} = 29.2 \text{ Ah} \therefore \boxed{\text{Use 12V, 30Ah Battery}}$$

8) Potential Snow Loading

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Pg. #1

G: Avg total liquid accumulation in Ellersburg = 1.2"
 * weatherspark.com
 Area of Surface = 2.316 ft²

F: Potential Loading due to Snow, @ 45° & 0°
 (In-operation & Max load)

M: ① Snow, Volume
 ② Snow, ρ
 ③ Mass = ρ · V
 ④ F = Mg

S: ① $h = (1.2'') \left(\frac{1'}{12''} \right) = 0.1 \text{ ft}$

$(2.316 \text{ ft}^2 \cdot \cos(45)) \cdot 0.1 \text{ ft} = \underline{0.1638 \text{ ft}^3} @ 45^\circ = V_1$
 $2.316 \text{ ft}^2 \cdot 0.1 \text{ ft} = \underline{0.2316 \text{ ft}^3} @ 0^\circ = V_2$

② Wet snow, assume 1516 / ft³ = ρ

③ $M = \rho \cdot V$
 $= (1516 / \text{ft}^3) \cdot (0.1638 \text{ ft}^3) \Rightarrow \underline{2.456 \text{ lb}_m} = M_1$
 $= (1516 / \text{ft}^3) \cdot (0.2316 \text{ ft}^3) \Rightarrow \underline{3.474 \text{ lb}_m} = M_2$

④ $F = Mg$
 $F_{@45^\circ} = (2.456 \text{ lb}_m) \cdot (32.17 \text{ ft/s}^2)$
 $F_1 = 79 \text{ lbf}$

$F_{@0^\circ} = (3.474 \text{ lb}_m) \cdot (32.17 \text{ ft/s}^2)$
 $F_2 = 111.8 \text{ lbf}$

9) Wind loading

Alazone Smith	MET 489A	Nov. 12, 2018	pg. #1
---------------	----------	---------------	--------

G: Area of Surface
Avg. $V_{wind} = 6.6 \text{ mph}$ (Nov. - Mar.) * weatherspark.us - com

F: Wind loading

M: ① V_{max}
② $P = 0.00256 V^2$
③ C_d
④ $F_w = A \cdot P \cdot C_d$

S: ① V_{max}
S.F. = 2
 $V_{max} = 6.6 \text{ mph} \cdot 2 \Rightarrow 13.2 \text{ mph}$
 $A = \left[\left(\frac{24.25'' \cdot 13.75''}{12''/\text{ft}} \right) \cdot \cos 45^\circ \right] = 1.637 \text{ ft}^2$
② P
 $P = 0.00256 V^2$
 $= 0.00256 (13.2 \text{ mph})^2$
 $P = 0.4461 \text{ psf}$
③ Assume $C_d = 1.4$, flat plate
④ $F = A \cdot P \cdot C_d$
 $= (1.637 \text{ ft}^2) \cdot (0.4461 \text{ psf}) \cdot 1.4$
 $F_w = 1.022 \text{ lbf}$

10) Stagnation Pressure

Alarone Smith	MET 489A	Nov. 12, 2018	Pg. #1
---------------	----------	---------------	--------

Gi: $V_{\text{wind}} = 6.6 \text{ mph (avg)}$
 $\rho_{\text{air}} = 1.225 \text{ kg/m}^3$, sea level @ 15°C

F: Stagnation Pressure

M: ① V_{max}
N: ② Stagnation Pressure

S: ① $V_{\text{wind}} = 6.6 \text{ mph avg.}$
 $S.F. = 2$
 $V_{\text{wind max}} = 6.6 \text{ mph} \cdot 2 \Rightarrow 13.2 \text{ mph}$
 $V_{\text{max}} = 5.9 \text{ m/s}$

② $P = \frac{1}{2} \rho V^2$
 $= \frac{1}{2} (1.23 \text{ kg/m}^3) (5.9 \text{ m/s})^2$
 $P = 21.3 \text{ N/m}^2$

11) Central Shaft Deformation & Stress

Alazone Smith	MET 489A	Nov. 29, 2018	g.# 1
---------------	----------	---------------	-------

G: Shaft OD = 2" = D
ID = 1.75" = d
Matl. = Aluminum 6061-T6
F = 25 lbs.
L = 12"

F: - Deformation due to axial load, on Central Support Shaft
- Direct Tensile Stress

M:

- ① E,
- ② A,
- ③ $\delta = FL/EA$
- ④ $\sigma = F/A$

S:

E = 10,000 ksi * Matweb.com
 $A = \pi(D^2 - d^2)/4$
 $= \pi(2^2 - 1.75^2)/4$
 $A = 0.736 \text{ in}^2$

$\delta = \frac{(25 \text{ lbs.})(12 \text{ in})}{(10,000 \text{ ksi})(0.736 \text{ in}^2)}$

$\delta = 0.041 \text{ in}$


$\sigma = 25 \text{ lbs} / 0.736 \text{ in}^2$

$\sigma = 33.97 \text{ psi} \approx 34 \text{ psi}$

12) Actuator Start Position

Alazone Smith	MET 469A	Nov. 29, 2019	pg #1
---------------	----------	---------------	-------

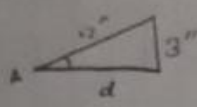
G:



Link, $L = 12''$
 d
 No lower than $3''$.

F: - Min. d for start position,
 - Angle of declination

S: @



$$12^2 = d^2 + 3^2$$

$$d = \sqrt{12^2 - 3^2}$$

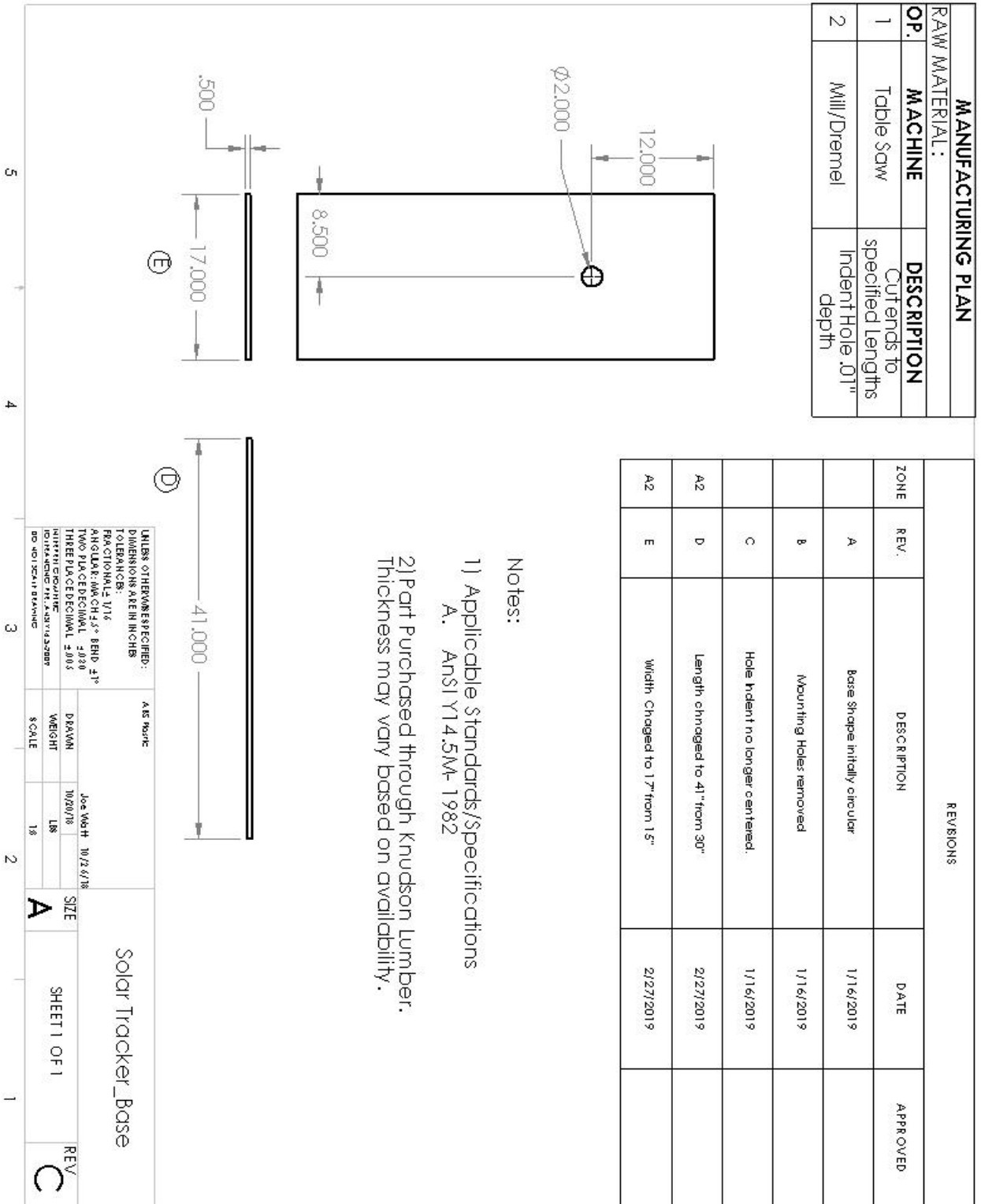
$d = 11.6''$ of extension for start position

$11.6'' = d_{min}$, @ $\angle A = \cos^{-1}\left(\frac{3^2 + 11.6^2 + 12^2}{2(3 \cdot 12)}\right)$

$\angle A = 14.3^\circ$

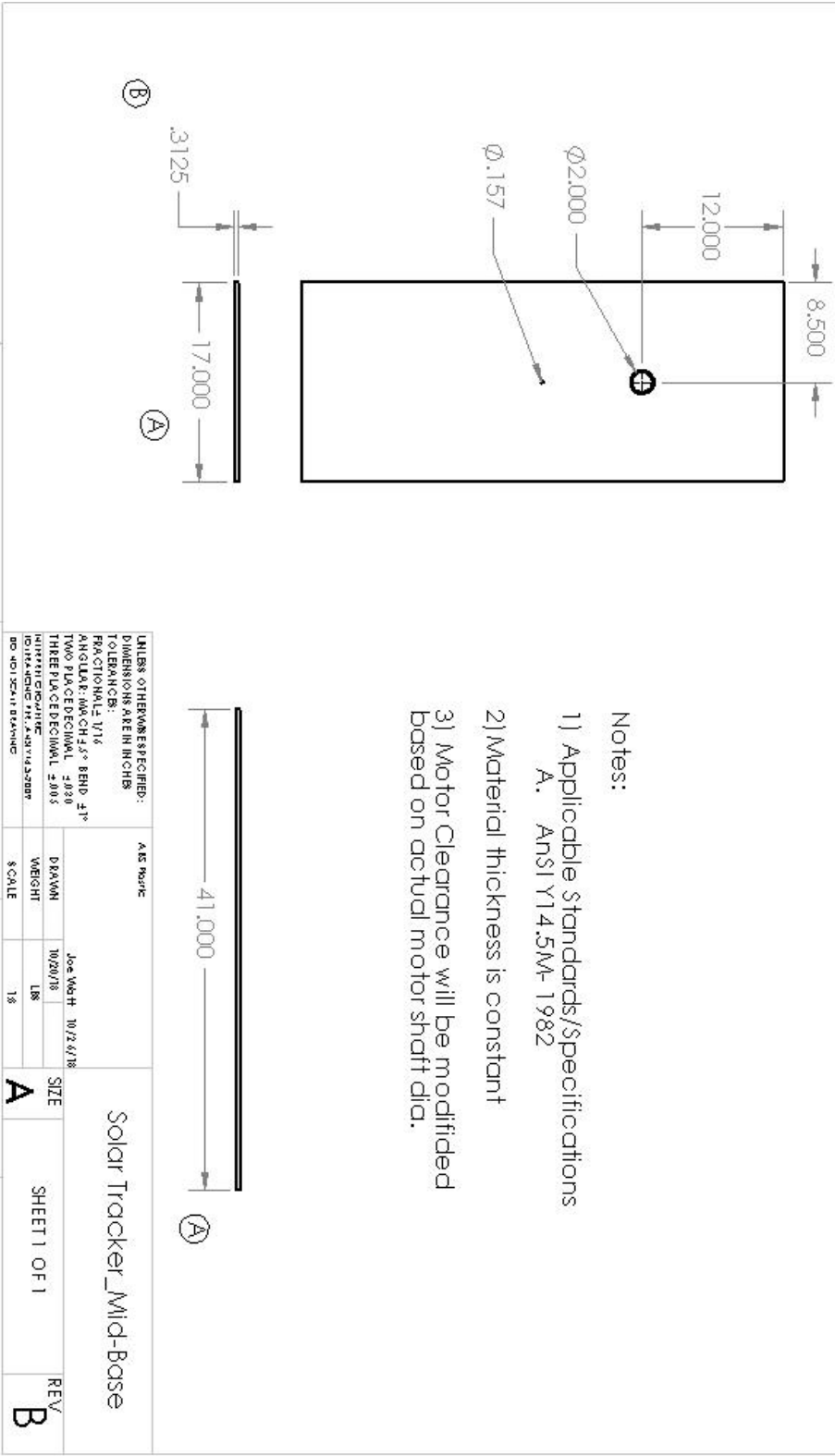
Appendix B

1) Lower Base

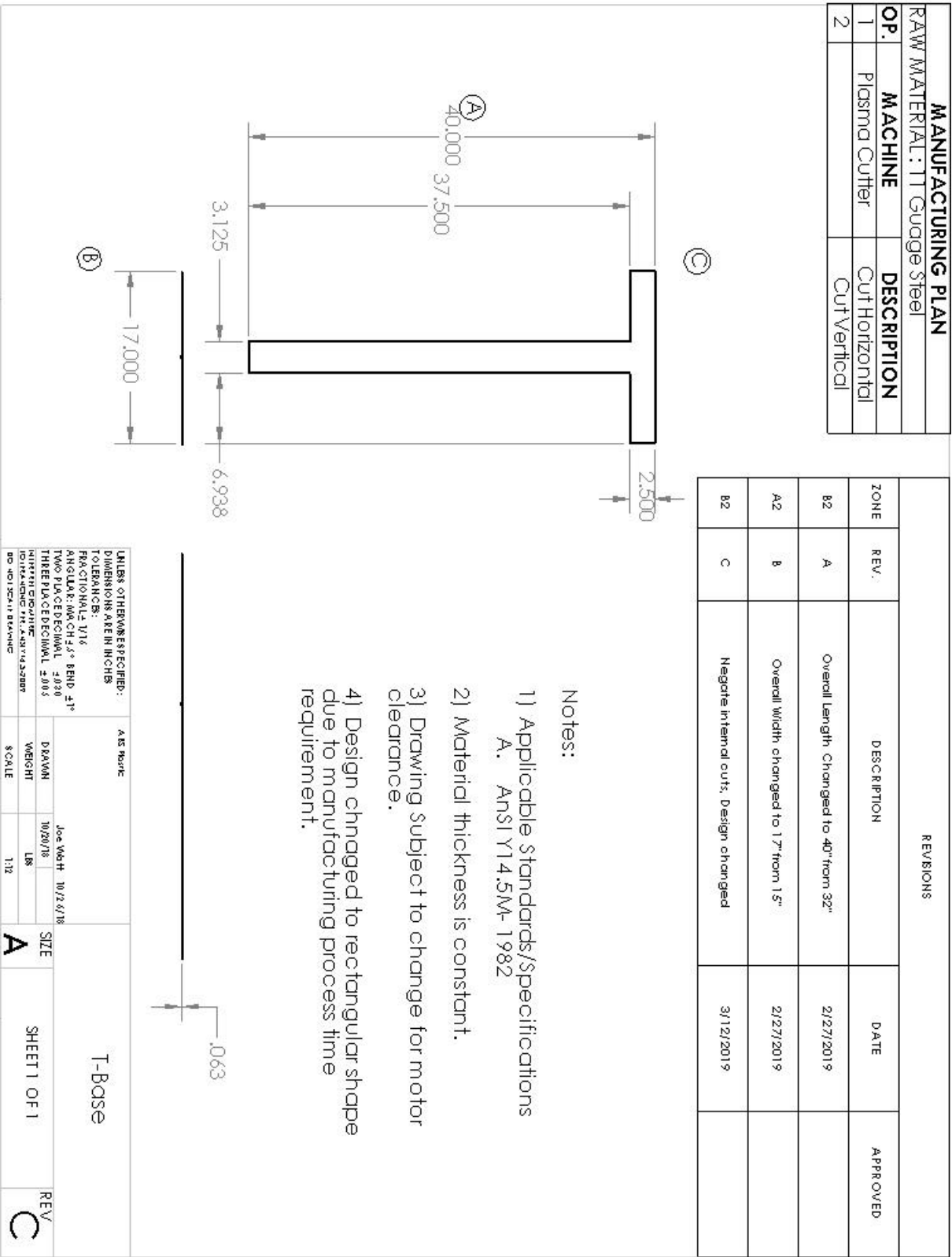


MANUFACTURING PLAN			
RAW MATERIAL:			
OP.	MACHINE	DESCRIPTION	
1	Table Saw	Cut ends to specified length	
2	Mill	Cut Larger Hole through all	
3	Dremel	Cut motor shaft hole	

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED
A1, A2	A	Length and Width Changes to match Base.	2/27/2019	
A2	B	Thickness changed to 3/8" from 1/2"	2/27/2019	

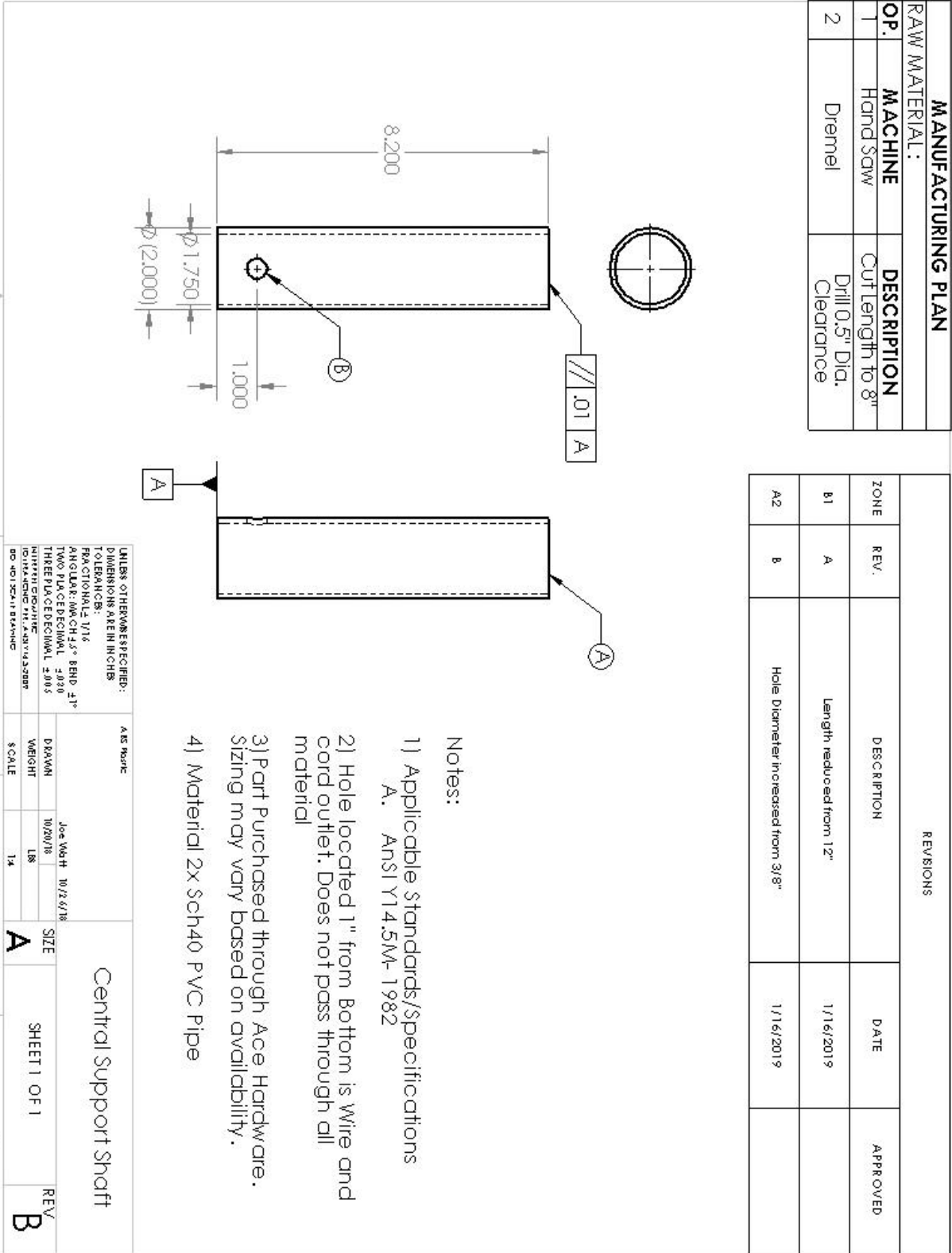


2) Mid Base



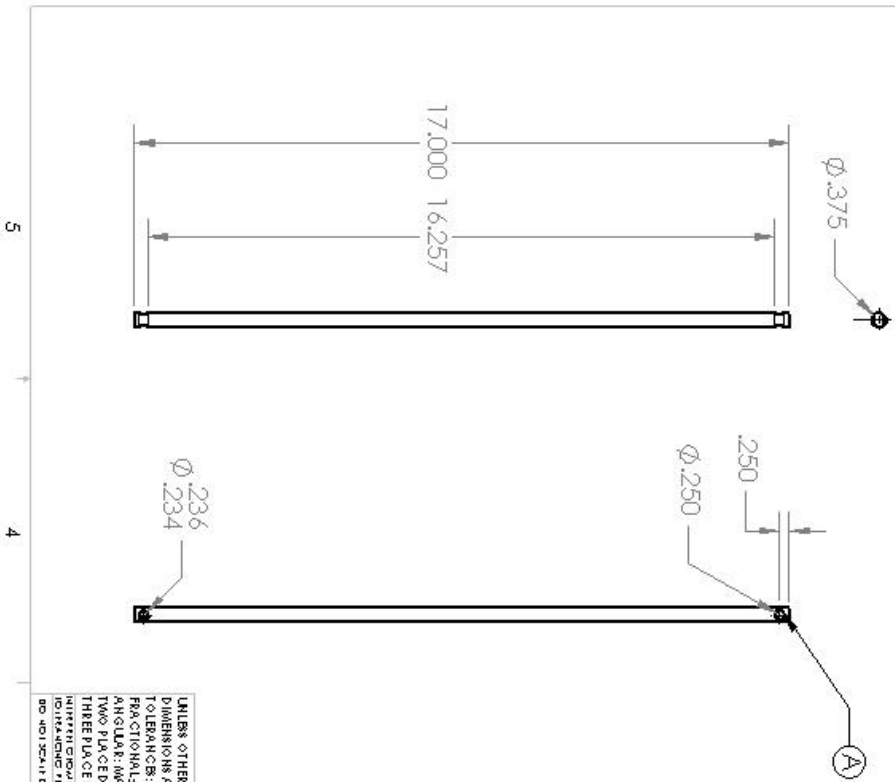
3) T-Platform

3) Central Support Shaft



MANUFACTURING PLAN		
RAW MATERIAL:		
OP.	MACHINE	DESCRIPTION
1	Dremel	Cut to specified length
2	Dremel/Mill	Cut bottom Hole with .236" Dia.
3	Dremel/Mill	Cut Top Hole with .250" Dia.

REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED
	A	Hole diameter increased from .236"	1/16/2019	



Notes:

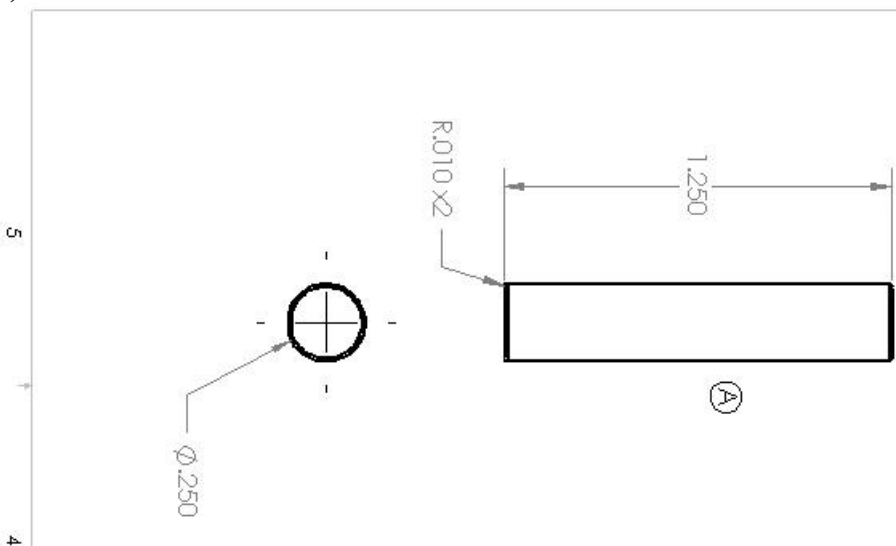
- 1) Applicable Standards/Specifications
A. ANSI Y14.5M-1982
- 2) Both holes through all material. Diameter of bottom hole is critical to actuator alignment
- 3) Part Purchased through Ace Hardware. Sizing may vary based on availability.

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL 1/16 ANGULAR: MACH 45° BEND 41° TWO PLACE DECIMAL ±.030 THREE PLACE DECIMAL ±.005 HYPOTHENUSE DOWEL PINS: .4375 DIA. 2.000 L		DATE		SIZE		REV	
DRAWN		Joe Watt		10/24/18		A	
WEIGHT		LB		18		A	
SCALE		1:1		A		A	

4) Connector Rods

DESCRIPTION	Cut to Specified length	Grind Fillet (Approx.)
-------------	----------------------------	---------------------------

ZONE	REV.	DESCRIPTION	DATE	APPROVED
B2	A	Length changed to 1.25" from 1.00"	3/12/2019	
A2	B	Purchased material will be threaded	3/12/2019	



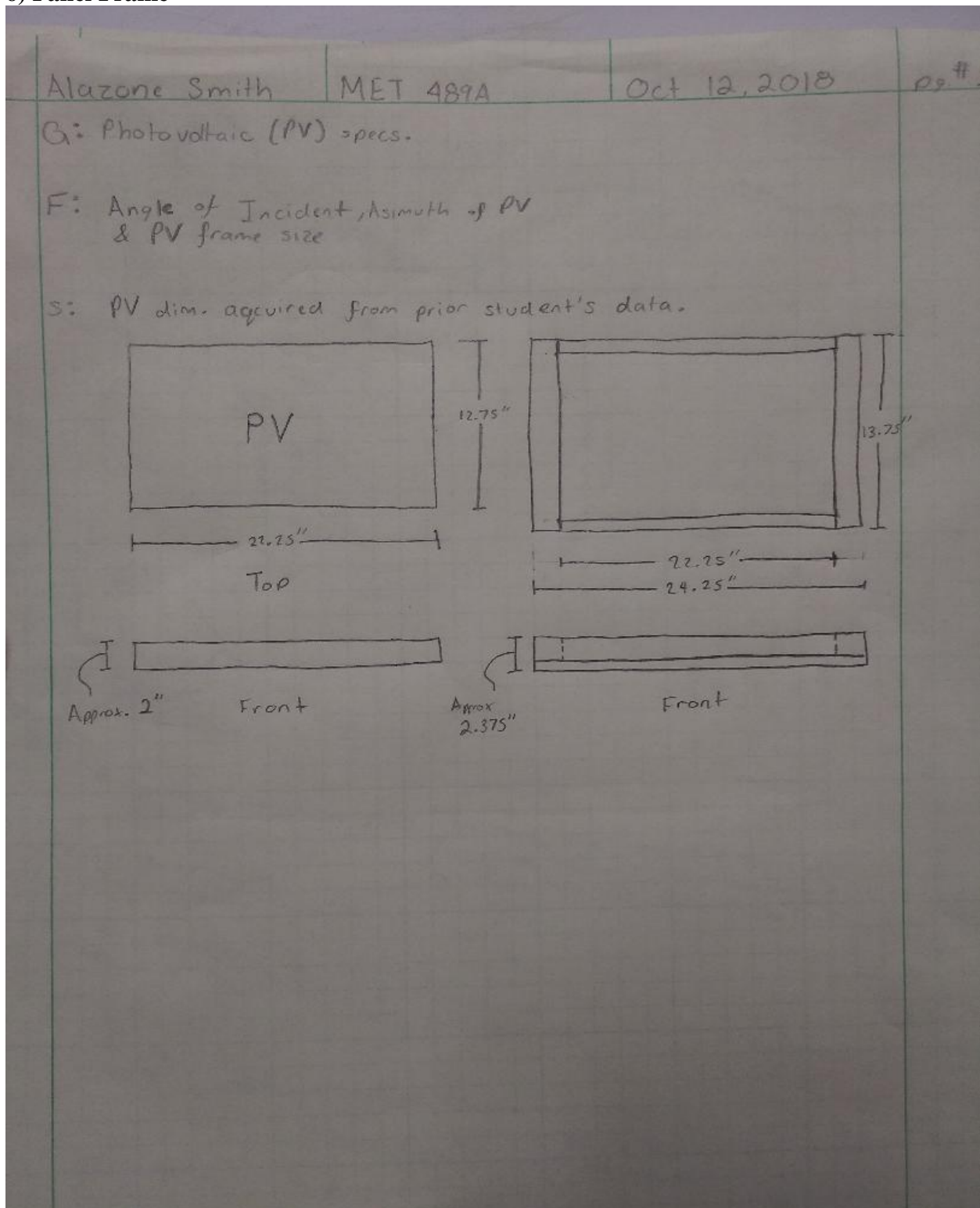
Notes:

- 1) Applicable Standards/Specifications
A. ANSI Y14.5M-1982
- 2) Material thickness is constant.
- 3) Purchased Material is threaded.

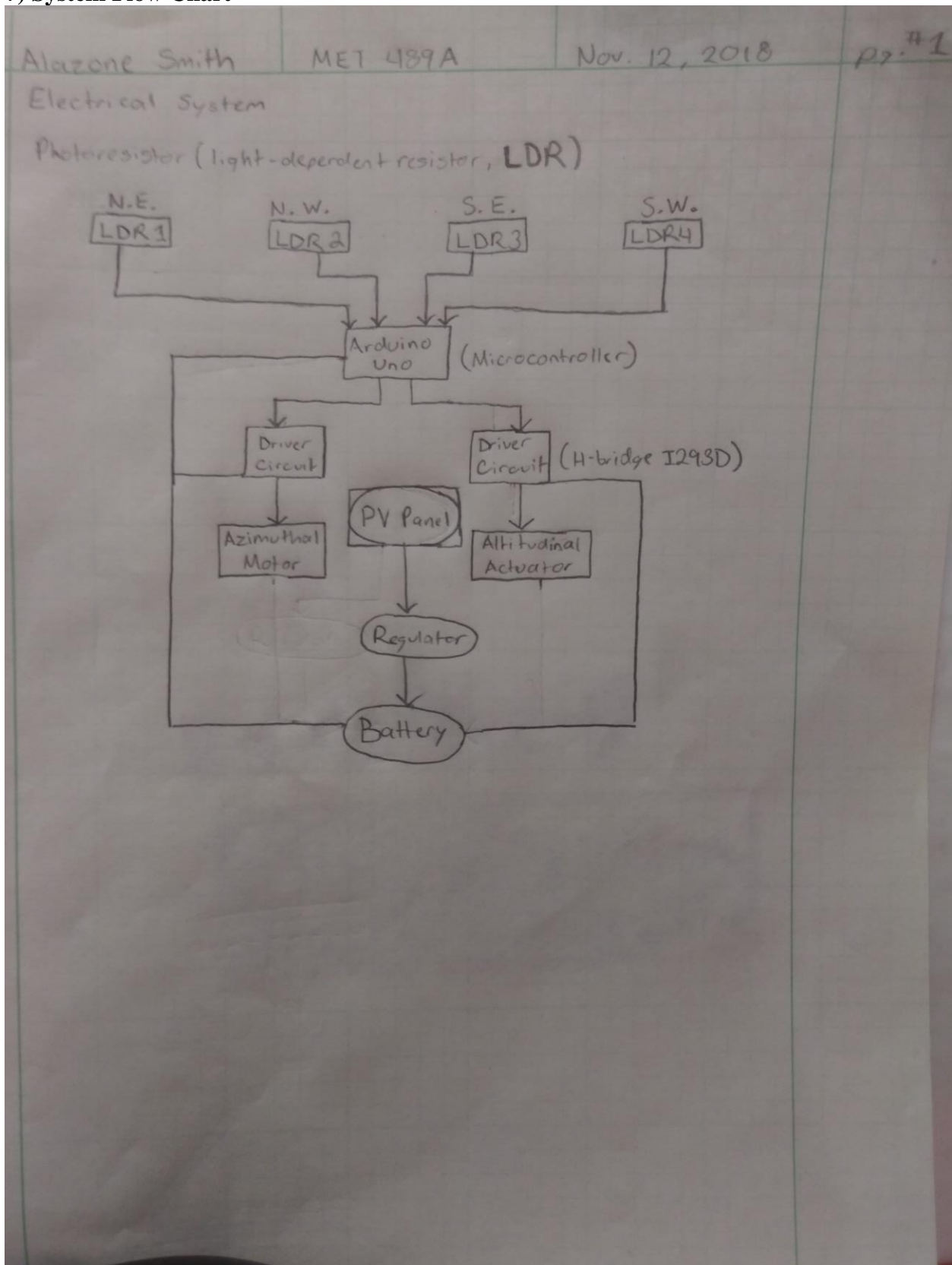
[illegible]

5) Aluminum Dowels

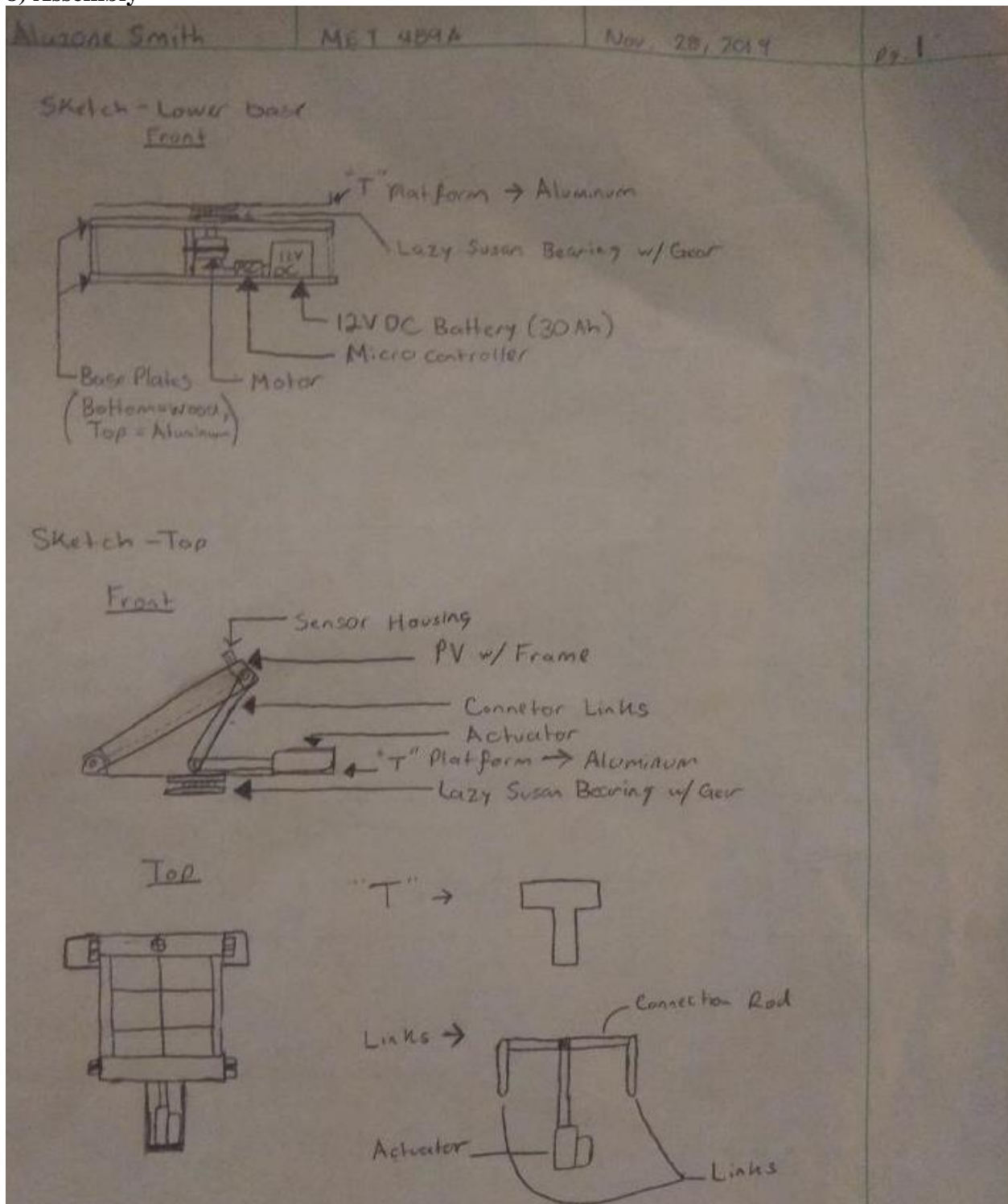
6) Panel Frame



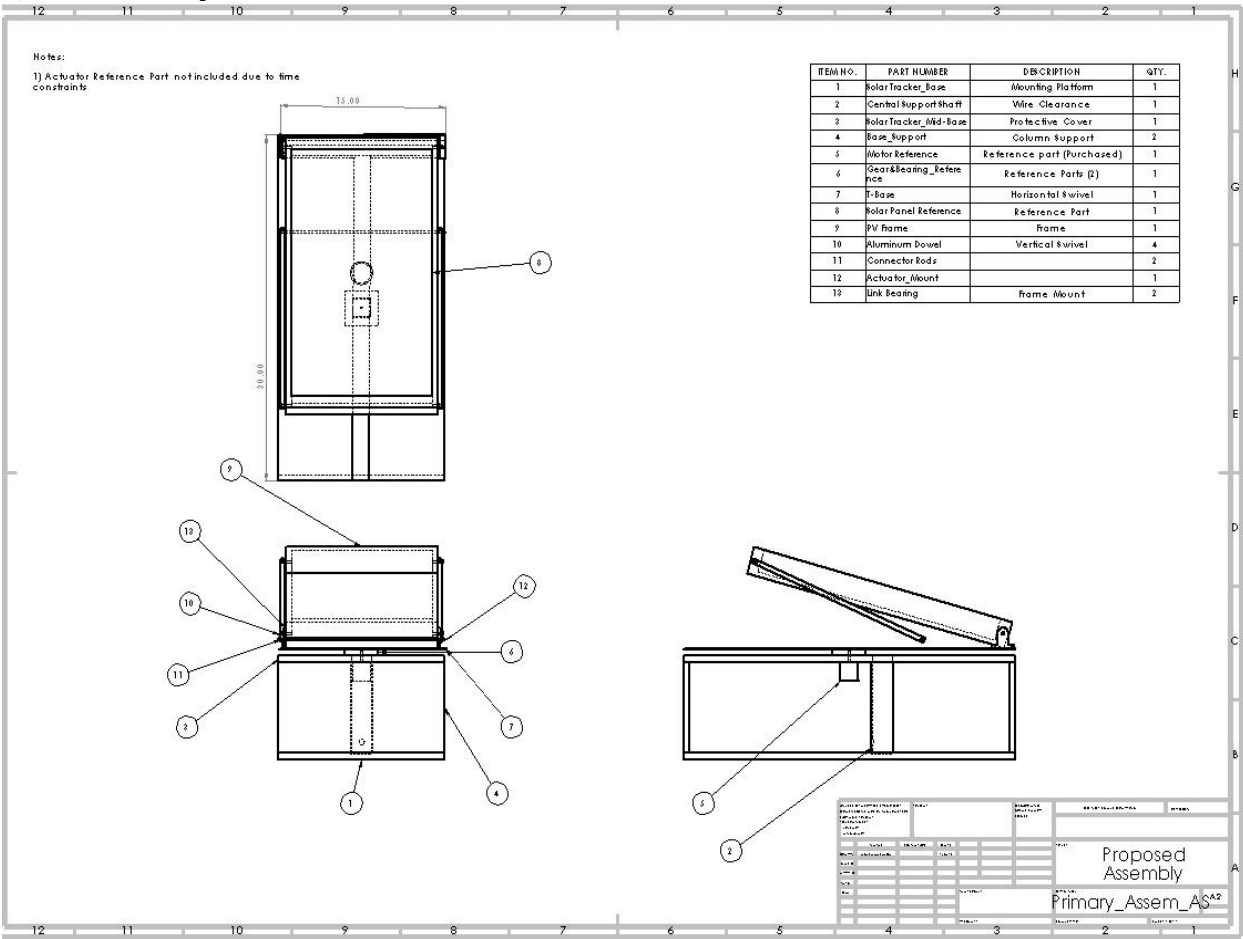
7) System Flow Chart



8) Assembly



9) 3D Assembly



Appendix C

1) Budget

Proposed Budget								
SENIOR PROJECT TITLE: Solar Tracker								
Item ID	Item Description	Item Source	Brand Info	Model/SN	Cost (\$ or \$/Hr)	Quantity (or hrs.)	Cost Sub.	Actual Cost
1	2'x1'x5/8" Wood	CWU	Wood Shop	N/A	0	1	0	0
2	.5"x1'x5/8" Wood	CWU	Wood Shop	N/A	0	2	0	0
3	#8 Screws	Ace Hardware	SPAX	N/A	2.79	1	2.79	3.01
4	12"x12"x.125" Sheet Metal	Amazon	M-D Building	56032	5.98	2	5.98	6.46
6	Motor Driver	Amazon	Qunqi	MK-050	6.89	1	6.89	7.44
7	Actuator	Amazon	SOVik	S300-100-12-75	48.99	1	48.99	52.91
8	Aluminum Shaft	Ace Hardware	K&S	5024005	0.99	2	0.99	1.07
9	Arduino	CWU	Arduino	N/A	0	1	0	0
10	Motor	DigiKey	Makeblock Co., LTD.	1890-1032-ND	22.99	1	22.99	24.83
11	Solar Regulator	Amazon	Jekewin	43223-29854	8.00	1	8	8.64
12	Aluminum Rods	CWU	N/A	N/A	0.00	4	0	0
13	"Lazy Susan" Bearing	WWExpress	TRIANGLE MFG. CO.	11448	8.10	1	8.1	8.75
14	EET Assistance	CWU	N/A	N/A	11	3	33	33.00
15	Assorted Aluminum	CWU	N/A	N/A	0	~	0	0
16	Battery	Apex Battery	EnerSys	NPC30-12	49.99	1	49.99	53.99
17	Sensor Housing	CWU	CWU	N/A	15	1	15	16.20
							Total=	\$216.30

Notes:

-Assume Sales Tax = 8%, use for Actual Cost

2) Official Acquisition List

Item ID	Item Description	Item Source	Brand Info	Cost (\$ or \$/Hr)	Quantity (or hrs.)	Actual Cost
1	2"x6"x8' Wood	Knudson	N/A	\$3.00	1	\$3.00
2	Assorted Wood	CWU	Wood Shop	\$0.00	6	\$0.00
3	Fasteners & Nuts	Ace Hardware & CWU	Ace Hardware & N/A	\$5.96	N/A	\$5.96
4	Sheet Metal	CWU	Wood Shop	5.98	1	6.46
6	Motor Driver	Amazon/ CWU	Ada fruit	N/A	1	\$0.00
7	Actuator	Amazon	SOVik	48.99	1	\$50.89
8	6mm Aluminum Shaft	CWU	N/A	\$0.00	1	\$0.00
9	Arduino UNO	CWU	Arduino	\$0.00	1	\$0.00
10	Stepper Motor + Braket	Amazon	NEMA 17	\$59.50	1	\$59.50
11	Solar Charge Controller	Amazon	PMW	\$11.99	1	\$12.99
12	Threaded Aluminum Rod – ¼"	Ace Hardware	Ace Hardware	\$4.49	4	\$4.49
13	3" Lazy Susan Bearing	Amazon	Amazon	\$5.99	1	\$6.44
14	12" Lazy Susan Bearing	Ace Hardware	N/A	\$14.99	1	\$14.99
15	EET Assistance	CWU	N/A	\$0.00	6	\$0.00
16	Adhesives	Ace Hardware	Gorilla Glue & Wild Bond	\$13.24	2	\$13.24
17	Battery	CWU	N/A	\$0.00	1	\$0.00
18	Sensor Housing	CWU	N/A	\$0.16	1	\$0.16
19	3/8" x 4' Aluminum Dowel	Ace Hardware	Ace Hardware	\$8.99	1	\$8.99
20	SCH40 Pipe 1"x 2'	Ace Hardware	N/A	\$0.92	1	\$0.92
21	LDR Sensors	Amazon	Gikfun	\$6.58	1	\$7.13
22	Rotary Tools	Amazon	Neiko	\$15.99	1	\$17.32
23	8" Cable Ties	Ace Hardware	Ace Hardware	\$2.29	1	\$2.59
24	¼" Pillow Block Bearing	Amazon	Servo City	\$5.99	2	\$20.55
25	Assorted Metal	CWU	N/A	\$0.00	3	\$0.00
					Total =	\$246.41

The list above provides an up-to-date overview of all the materials acquired to complete this project. Taxes, as well as shipping and handling fees were all accounted for in the construction of this list.

Appendix D

1) Schedule

PROJECT TITLE: SOLAR TRACKER				Incomplete		(su)											
Principal Investigator: Alazone Smith				In Progress													
				Completed													
Duration																	
TASK:	Description	Est.	Actua	%Comp.	S. October	November	Dec	January	February	March	April	May	June				
ID		(hrs)															
1	Proposal																
a	Outline	1	0.5	100	X												
b	Intro	1	1.5	100	X	X											
c	Methods	2	3	100		X	X										
d	Analysis	20	25	100	X	X	X	X	X	X							
e	Discussion	4	3.2	100			X	X									
f	Parts and Budget	4	8	100			X	X									
g	Drawings	15	22	100	X	X	X	X	X								
h	Schedule	2	6.5	100			X	X	X	X							
i	Summary & Appx	6	5	100				X	X								
	subtotal:	55	74.7														
2	Analyses																
a	Solar Insolation	0.5	1	100	X												
b	Degrees of Rotation	0.25	0.2	100	X	X											
c	Actuator Loading	0.5	1	100	X	X	X	X									
d	Motor Torque	0.25	0.5	100		X	X										
e	Electrical Systems	1	1.5	100			X	X									
f	Snow Loading	0.5	1	100			X	X									
g	Wind Loading	0.5	0.5	100			X										
h	Staqnation Pressure	0.25	0.1	100			X										
i	Elevation Angle Range	1	1.5	100				X	X								
j	Critical Loading	2	1.4	100				X									
k	Sheet Metal Thickness	1	0.7	100					X								
l	Holding Torque	1	2.6	100						X							
	subtotal:	8.75	8.7														
3	Documentation																
a	Part 1 - Base/Mount	1	1	100	X	X	X										
b	Part 2 - Central Shaft	1	0.5	100		X	X	X									
c	Part 3 Vertical Support	1	0.5	100			X										
d	Part 14 Panel Frame	1		100		X	X	X									
e	System Flow Chart	1	1	100			X	X	X								
f	Part 10 Sheet Metal "T"	0.5	0.7	100				X	X								
g	Part 11 Mounting Bearing	0.5	0.9	100					X								
h	Part 12 Connector Links	0.5	0.8	100					X								
i	Part 4 Base Cover	1	0.6	100					X	X							
j	Part 15 Senor Housing	1	0.2	100					X								
k	Assembly + BOM	8	5.2	100					X								
l	Website Update	1	3.2	100						X							
m	Kinematic Check	1	1.5	100					X								
n	ANSIY14.5 Compl	3	1	100						X							
o	Make Object Files	8	3	100						X							
	subtotal:	29.5	20.1														
4	Proposal Mods																
a	Project Schedule	3	1.5	100						X							
b	Project Part Inv.	2	1.5	100						X							
c	Crit Des Review*	3	2	100						X							
	subtotal:	8	5														
7	Part Construction																
a	Purchase Frame Wood	1	6	100				X									
b	Purchase Base wood	0.5	1	100				X									
c	Purchase Actuator	3	2.5	100				X									
d	Purchase "Lazy Susan"	1	0.5	100				X									
e	Print Sensor Housing	2	2.5	100					X								
f	Locate EET Assitant	2	2.7	100					X								
g	Manuf. PV Frame Components	4	4.4	100						X							
h	Manuf. Connetor Links	1	1.2	100						X							
i	Purchase P.B. Bearings	0.5	0.8	100						X							
j	Manuf. Actuator Link	2	0.8	100							X						
k	Aquire Sheet Metal	6	2	100							X						
l	Manuf. "T-Platform"	2	1.1	70							X						
m	Manuf. C.S.S	1	4	100								X					
n	Manuf. Base Components	4	1.9								X						
o	Aquire Motor	1	1.2	100								X					
p	Aquire Rem. Electrical Comp.	2	1	100									X				
q	Take Part Pictures	2	2.8	100										X			
r	Update Website	2	3.1	100											X		
s	Manufacture Plan*	15	8.3	100											X		
	subtotal:	52	47.8														

Appendix F

1) Expertise and Resources TBD.

Appendix G

1) Testing Data

Actuator – Test 1				
Trail	Time – Collapse (s)	Time – Return (s)	Max Length (in)	Angle of Declination
1	40.14	22.21	9	36.87
2	39.26	21.67	9.25	38.07
3	41.03	23.11	8.875	36.28
4	39.73	21.82	9.125	37.47
5	40.36	21.36	9.125	37.47
Avg.	40.10	22.03	9.08	37.23

Completed Test

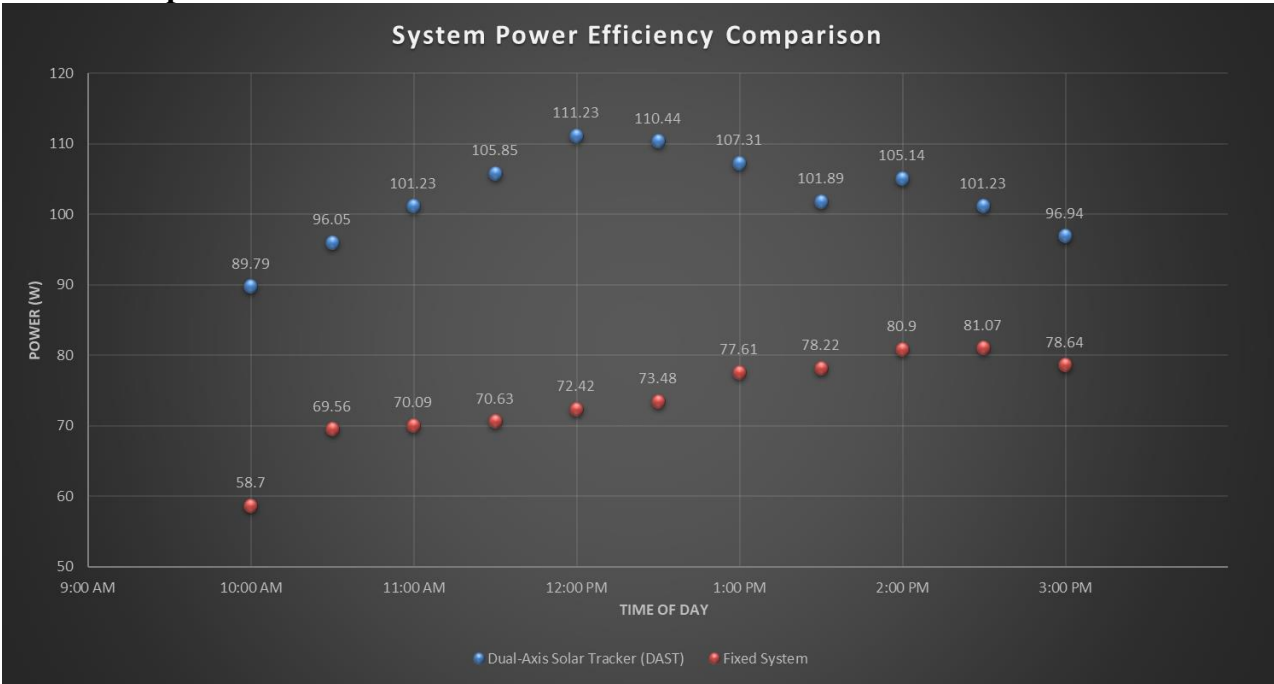
Motor - Test 2			
Trail	Components Removed	Approx. Weight*	Observation
1	None (Full Assembly)	~28 lbs.	No rotation
2	Panel (P) & Frame (F)	~18 lbs.	No rotation
3	P, F, Actuator & Links	~13 lbs.	No rotation
4	All components	0 lbs.	Motor operational

*Approximate weight resting on motor and adapter

Power Efficiency Test

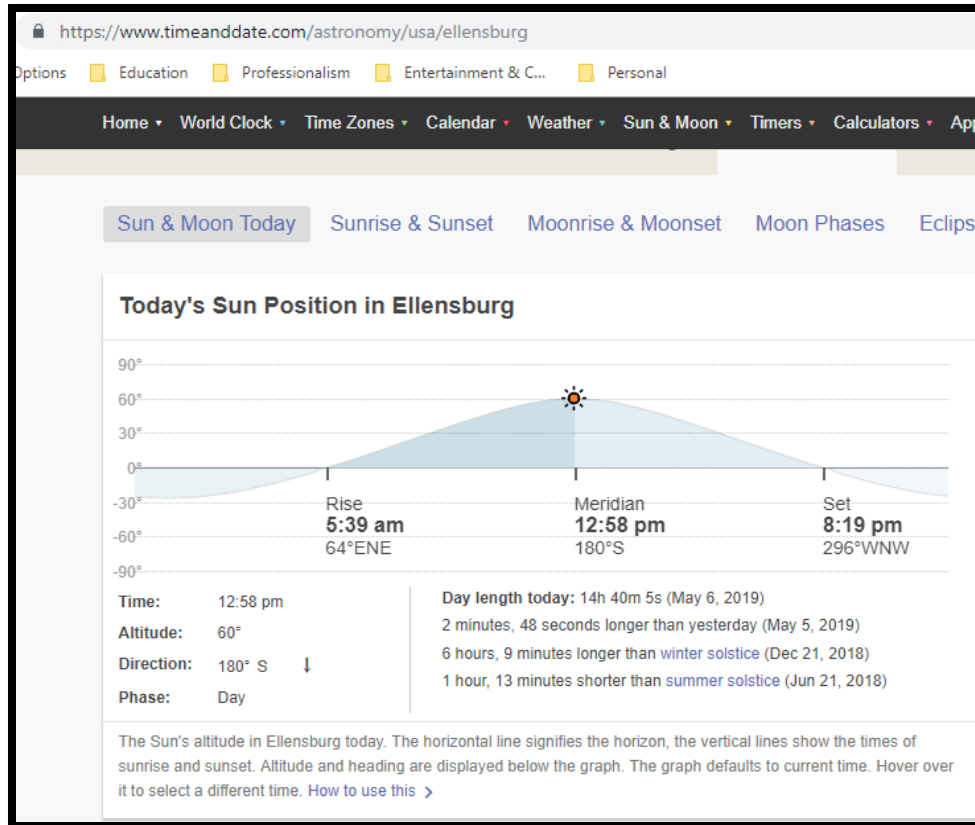
Constants		Dual-Axis Tracking System (DAST)				Fixed System		
Time	Alt. (°)	Angle (°)	Volts (V)	Amps (A)	Power (W)	Volts (V)	Amps (A)	Power (W)
10:00 am	41	115 ESE	14.14	6.35	89.79	11.42	5.14	58.70
10:30 am	46	124 ESE	14.23	6.75	96.05	12.81	5.43	69.56
11:00 am	50	130 SE	14.80	6.84	101.23	12.86	5.45	70.09
11:30 am	51	142 SE	15.43	6.86	105.85	12.94	5.45	70.63
12:00 pm	53	154 SSE	15.71	7.08	111.23	13.12	5.52	72.42
12:30 pm	53	167 SSE	15.89	6.95	110.44	13.24	5.55	73.48
1:00 pm	53	180 S	15.44	6.95	107.31	13.45	5.77	77.61
1:30 pm	53	194 SSW	15.14	6.73	101.89	13.51	5.79	78.22
2:00 pm	53	207 SSW	15.26	6.89	105.14	13.62	5.94	80.90
2:30 pm	51	218 SW	14.96	6.76	101.23	13.49	6.01	81.07
3:00 pm	50	230 SW	14.71	6.59	96.94	13.42	5.86	78.64
Averages	50.4		15.06	6.80	102.46	13.08	5.63	73.76

Test 3 - Graph

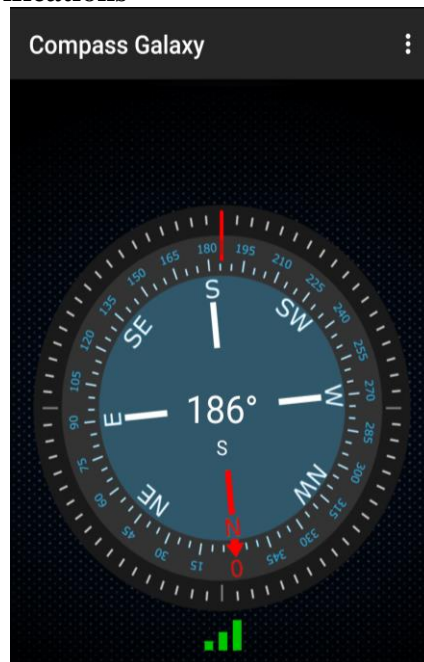


Appendix H

1) Sun Altitudinal & Azimuthal Axis



2) Solar Tracker Position Verifications



Appendix I

1) Testing Report

i. Introduction

This test report addresses the setup, result and analysis of both drivers within the device. The drivers are essential to the viability of the device and such they must be tested first. The actuator must be able to provide max and min angles of declination suitable for the testing conditions in Ellensburg which is between 51 and 43 degrees, respectively. The angle of declination will have a large effect on the energy efficiency. The motor must provide full range of motion (min. 180 degrees) to allow the system to track the sun throughout the day. Based on the calculations performed in the previous sections the actuator will provide a range of 55 to 38 degrees for the angle of declination, while the motor is expected to rotate completely but with limited speed due to the radial load. The following section will express the data collected during the last week of March and the third week of April (Appendix D).

ii. Method/Approach

In order determine the angle of declination of the solar panel, the extension length of the actuator must be used in relation to the position of the solar panel. Please refer to the discussion sketch within the testing procedure section. The Pythagorean theorem is used to determine the angle between the actuator link and the solar panel frame (angle of declination). As the actuator extends this angle will decrease. The start position will provide the max angle while the full extension of the actuator will provide the minimum. The purpose of this test is to observe how far the actuator can extend for the system collapse on itself. The trials will program the actuator to continue to extend until the panel collapses, then that point will be marked and measured. The resulting length will be used to then determine the max extension length and the minimum angle of declination.

The motor test must be able to rotate at least 180 degrees. The purpose of this test was to ensure the motor could handle the load placed upon it while at the same time rotating along with the 15 degrees/ hour that the sun moves throughout the day. The biggest issue anticipated is that the deflection of the platform will create inference with the Lazy Susan bearing. So, the motor will run one full revolution at max speed in 15-degree intervals. The time it takes to complete the cycle will be recorded. Also, each moment where there is interference will be marked for further modifications or adjustments.

Resources:

- Ruler/Measuring Tape
- Timer
- Power Source (12V Battery)
- Marker
- Calculator

Data capture:

Data sheets have been created for each test and are provided on a Word doc. and can be referenced in Appendix G. Since the resulting data will only need to be analyzed using basic mathematics and visual observation there is no software requirements for processing the data.

The full overview of the test will succeed this section and provide an in-depth summary of each drivers steps for data collection along with the specifics of the testing conditions. However, it's important to acknowledge certain operational limitations that limit the procedure:

- The actuator only has a max extension length of 12 inches that limits the min. angle of declination
- Both drivers run on 12v dc power as well as 5A of power which limits the max speeds
- There is no need to test energy collection at this time, so the testing environment does not need to be performed outside.

The data collected is observed visually and with a measuring tape or ruler and should have a precision up to 1/16 in. Also, the tests are performed with the EET assistant to verify the data collection is accurate. Once all data is collected and recorded in the data sheets established, calculations for the angles of declination will be carried out by hand and verified with the calculator.net software found online. The conclusion to the analysis of this data is provided in the final portion of this testing report.

iii. Test Procedure

Summary:

The preliminary test for this device will focus on the functions of the both drivers. The actuator test be tested to determine the max and min angles of declination. The angle of declination will have a large effect on the energy efficiency. The motor must be tested for full range of motion; if it does not the range of motion must be specified to better position the system for future test.

Specify time, duration:

The full length of the test should run no longer than 20 min in total with approximately 5-8 mins of prep time in-between. The time will be divided between both drivers with 5 trials each. This is approximately 2 min. per trial. Reference the schedule (Appendix D) for the testing periods. The actuator test was conducted during the last week of March and the motor test was conducted during the second week of April.

Specific Place:

Testing will be conducted inside of the Hogue, Senior Project room.

Specific actions to complete the test:

Actuator

1. Take relevant measurements, it will be important for calculating angle of declination:
 - Max Height:
 - From actuator bar to highest pivot point of PV Frame
 - Max Length:
 - From initial actuator position to center of block bearing
 - PV Length:
 - From block bearing to center of highest pivot point on PV Frame
2. Connect the power supply, 12v battery to Micro-Controller.
3. Upload Program "A-Max"

- Program “A-Max”: Full extension of Actuator in 1 in increments, then return to start position
- 4. [Trial 1] start the program
- 5. Use a stop watch to record the time until collapse and the time till return. This will improve programming
- 6. Use a marker to indicate the point that the PV Frame collapses and record the length from the initial start position to the point of collapse.
- 7. Repeat 4-6 for Trials 2-5.
- 8. Once all the trials are complete, calculate the max. and min. angles of declination.

Motor

1. Upload Program “M-360”
 - Program “M-360”: 1 full revolution of the motor in 15-degree increments, then returns to start position.
2. [Trial 1] start the program
3. Use a stop watch to record the overall time for 1 revolution and the time till return. This will improve programming
4. Use a marker to indicate each point of significant interference or complete stops.
5. Repeat 2-4 for Trials 2-5.
6. Once all the trials are complete, make note of adjustments to be made to improve rotation efficiency of Motor.

Risk:

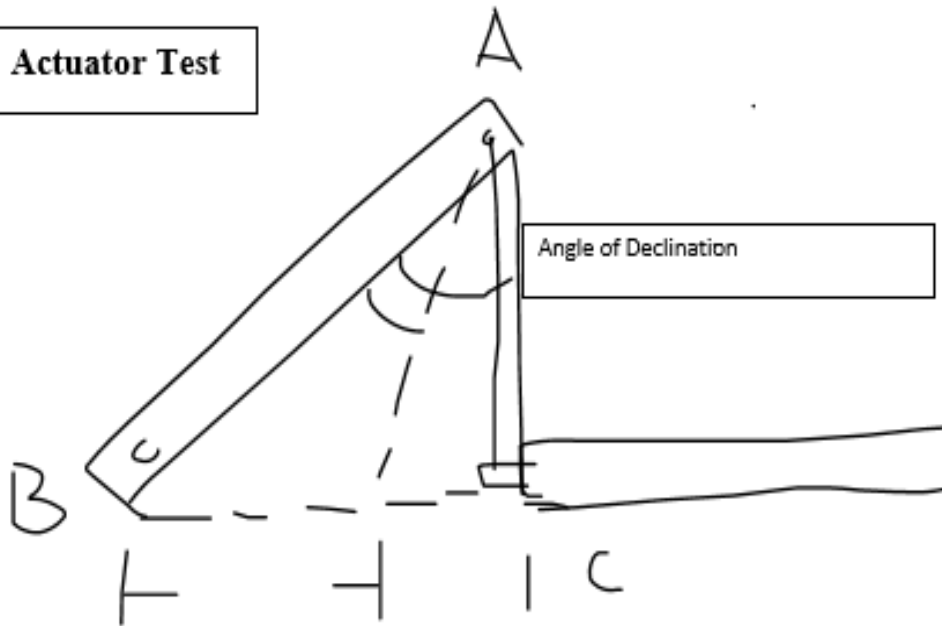
Insure device is operating with free range of motion and zero obstructing objects. It is also to limit all hazards to power supply and electronic components.

Discussion:

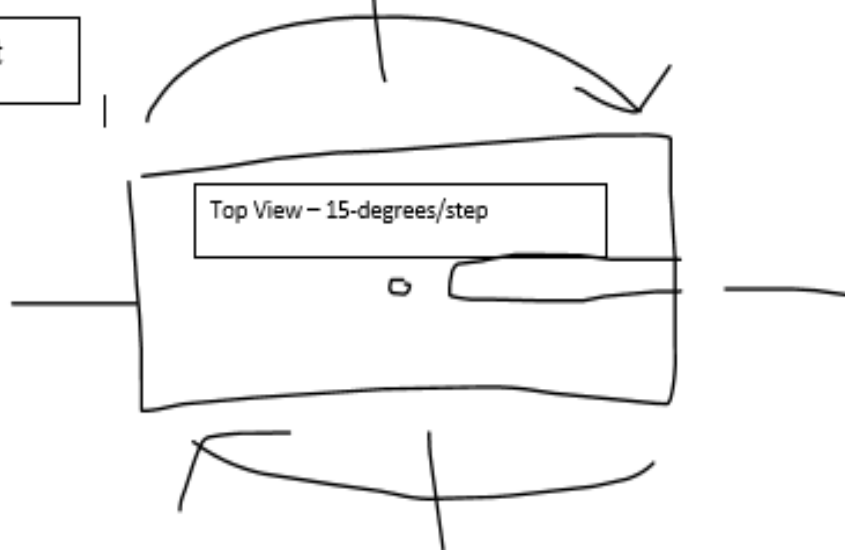
Provided below is rudimentary description of the testing operation for both drivers.

Discussion:

Actuator Test



Motor Test



iv. Deliverables

The complete testing data charts can be referenced in Appendix G while this section will summarize the conclusion of the data analysis. The actuator performed as intended with acceptable results and no further modifications were required. Initial Measurements:

- Max Height: 15 in.
- Max Length: 20 in.
- PV Length: 25 in.
- Max Angle of Declination: 53.13 Deg.

The max angle of declination is set from the start position and was deemed 2.1 degrees higher than the required Maximum angle. From the test the average of the focused parameters were as follows:

- Collapse Time: 40.1 s
- Return Time: 22.03 s
- Max Extension Length: 9.08 in
- Min. Angle of Declination (Calc.): 37.23

The minimum angle of declination was calculated at 5.77 degrees lower than the required min. angle of 43 degrees which was also acceptable. It should also be noted that the collapse time is based on interval movements while the return time is based on continuous movement.

The anticipated results of the motor specified that the revolution time along with return should take no longer than 1-2 minutes with zero interference. However, it may experience slowed rate of return with maximum weight that could add an additional minute to that expected revolution time.

Motor Results:

The motor test was meant to observe the interference frequency, speed, and time during one full revolution from the start position. However, the motor test has been deemed a failure due to several discrepancies. Initial test of the motor before installation to the system worked well but was unsuccessful when used in application.

Observation:

The motor would not move the system with all the components assembled and as a result, to better understand the issue, components were removed incrementally to see how much weight it could rotate. However, once all components except the platform it's mounted to were removed, the motor still would not rotate. The motor created a loud clicking sound that was determined to be either a slipping within the shaft adapter or within the motor itself.

Analysis: From the information gathered there was either an issue with how tightly fastened the adapter was to the motor shaft or that the radial load was too much to overcome. Since the motor was operational with all programs outside of application, the issue must be mechanical. Further calculation is required to determine if a stronger motor is needed also.

Outcomes:

Following this test further analysis of the decide the loading was concluded as the issue.

Therefore, the require torque to rotate the system must be redetermined. The rotational inertias of each component will be calculated then used along with the masses collected to calculate the torque. Once these are established, with the new torque calculation an analysis of current motor can establish the appropriate step to move forward. The initial idea is to construct a drive train or gear box to improve the torque, if viable.








Appendix J

1) Job Hazard Analysis

Job Hazard Analysis

Prepared by: Alazone Smith	Reviewed by: Approved by:
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Location of Task:	Central Washington University - Hogue
Required Equipment / Training for Task:	Training for operation of mill, drill and table saw. Also, PPE, including gloves, hard-frame safety glasses, and hard toe shoes.
Reference Materials as appropriate:	Appendix J

Personal Protective Equipment (PPE) Required						
(Check the box for required PPE and list any additional/specific PPE to be used in "Controls" section)						
						
Gloves	Dust Mask	Eye Protection	Welding Mask	Appropriate Footwear	Hearing Protection	Protective Clothing
<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Use of any respiratory protective device beyond a filtering face piece respirator (dust mask) is voluntary by the user.						

PICTURES (if applicable)	TASK DESCRIPTION	HAZARDS	CONTROLS
	Boring Holes for Mount	Flying Chips/Debris	Require training of boring machine, proper PPE (Eye Protection)
	Drilling Holes out of Sheet Metal	Flying Chips/Debris	Require training of drill, proper PPE (Eye Protection)
	Gear and Motor Operations	Hair/Clothing Grip	Extend base diameter to prevent accidental catching of clothing/hair.
	Saw base to size dimensions	Injury from cutting action	Required training of table saw
	Actuator Operations	Potential failure leading to falling parts	Ensure software meets specific distance requirements, Apply Safety Guard for potential collapse of panel.

Appendix K

1) Resume

Alazone Smith

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Professional Summary

At Central Washington University, I have taken a multitude of courses that have helped me refine my skills in the engineering discipline. I have gained much field experience on construction and project sites, which has allowed me to apply much of knowledge I have attained while in the MET program. I have found my passion in Project Management and it is my intention to begin my career experiencing travel or at the least city life. I wish to continue to pursue more challenges and be a part of a success-driven team, as I continue to learn more skills and improve upon the ones I already have.

Related Work Experience

June 2015 – July 2015: Great Western Coatings (Prosser, WA)

Laborer & Painter of Industrial warehouses

July 2015 – Sept. 2015: Bender's Handyman Services (Denver, CO)

Apprentice in plumbing maintenance, foundation support, concrete laying, Electrical Work, and other like work.

Aug 2018 – Present: Evergreen State Construction (Ellensburg, WA)

Laborer & Builder for various projects related to agriculture, foundation, and carpentry.

Education

1. Graduate at Gateway High school (Aurora, CO)
2. Central Washington University (Ellensburg, WA)
 - a. 3.2 GPA
 - b. Projected Graduation Date: June 2019
 - c. Mechanical Engineering Technologies
 - d. Douglas Honors College

Skills and Abilities

- | | |
|---|----------------------------|
| - Honors Spanish (Partially Bilingual, 4-years) | - Self-Motivated |
| - Proficient Microsoft Office skills | - Founder of Two Start-ups |
| - Intermediate AutoCAD Skills | - HoloHome. LLC |
| - Solidworks Certified | - Silverline Design. LLC |
| - MS Project | - Organized |
| - Excellent Verbal Communication | - Effective Problem Solver |
| - High Attention to Detail | - Team Player |

References

Available upon request

Appendix L

Dual Axis Solar Tracker: Trends, Influence & Impact

Alazone Smith

Senior Capstone
Submitted in Partial Fulfillment of the Requirements for Graduation from
The William O. Douglas Honors College
Central Washington University

June 2019

Accepted by:

_____ Committee Chair (Name, Title, Department)	_____ Date
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_____ Committee Member (Name, Title, Department)	_____ Date
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_____ Director, William O. Douglas Honors College	_____ Date
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ABSTRACT

This supplementary document examines the international relevance and impact of the device in the Central Washington University, M.E.T. Senior Project entitled, “Dual-Axis Solar Tracker”. This is done so by analyzing the data collected from the device, as well as related trends in society, and establishing connections between the device’s viability and its impact within the society. Climate change, the solar industry, technology, policy, and market are the main topics of research within this document to provide background and context for the methods of analysis. Following intensive research, two major research strategies were implemented: (1) the data collected from the device during the testing phase of the MET489 Course is used to conduct a quantitative comparison to similar real-world models and evaluate its performance; (2) the project’s marketability is also analyzed, to make an educated hypothesis of changes that can be made in potential iterations. This supplementary document expands upon the testing analysis of the device to provide a more in-depth representation of its current and potential impact. The device was being analyzed for its ability to be a promising economic investment as well as a solution to global challenges.

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Introduction

This purpose of this document is to fulfill the academic requirements of the Douglas Honors College's (DHC) Upper Division Capstone Project. It is also intended to be complementary supplement for the Mechanical Engineering Technologies (MET) Senior Project by the principal engineer, Alazone Smith, entitled, "Dual-Axis Solar Tracker". The device will be referenced as DAST throughout this document. All research, coursework, and documentation has been completed at Central Washington University (CWU).

1.a) MET Project

Overview

The goal of the MET Senior Project is to develop a device that demonstrates the principle engineer's knowledge of engineering, physics, mathematics, and materials science by designing, manufacturing, and analyzing a mechanical system. Based on the principle engineer's experience and interest, a dual-axis solar tracker was the prime candidate for achieving this goal.

"Solar power is actually a bargain with the subsidies that are now available. The installed cost of solar has gone down 95 percent since 1970 and is expected to go down even more with massive deployment and thin-film technology in the near future. And who can put a cost on the health benefits of cleaner air and the environmental benefits of stopping or at least slowing global warming." – David Freeman, *Winning Our Energy Independence*, 2007.

The quote above was chosen because it acknowledges some of the important concepts that will be discussed throughout this report. First, it provides some perspective on how dramatically an industry or technology can change over the course of several decades. Specifically, how solar energy evolved in terms of social perception, physical form, and influence on the economy. Analyzing the major contemporary developments from technology, social progress, and policy related to the solar-industry helps to explain the connection between this device and the future of this technology. Also, the collected data from the device was used to conduct a quantitative comparison to similar real-world models and evaluate its performance, marketability, and viability.

Progress

The document entitled, "Dual-Axis Solar Tracker" is an in-depth report of the principal engineer's experiences while designing, constructing, and testing a dual-axis solar tracker (DAST). The specifics of solar trackers will be outlined later, in the methods section. The project is divided into the three phases aforementioned; design, construction, and testing.

The design phase was conducted during the 2018 Fall quarter. After the project object was established a detailed schedule, budget, and plan were developed to improve the project success rate and the engineer's project management skills. The ground work established during this time included, numerous sketches, analysis, calculations, manufacturing drawings, and documentation all in accordance with ANSI Y14.5 standards. All the relevant data can be reviewed within said document.

Construction took place during the Winter 2019 quarter. This phase will be mostly related to this thesis as it addresses current materials being used for a solar-energy project today, as well as standard procedure within the manufacturing industry. The project consists of two major systems; a mechanical structure and an electrical interface. The principal engineer works primarily on the construction of the mechanical structure, but also solidifies the electrical plan to be implemented by the Electrical Engineering Technologies (EET) assistant. Over the course of the quarter a substantial amount of time was used to locate resources. There are meetings with various students, faculty and suppliers to obtain advice, supplies and even general information. The true value in this phase lies not in the completion of the project however, but in the principal engineer's ability to mitigate risk and improvise when problems arise.

Lastly, the testing phase was conducted during Spring 2019 quarter. Once the project was complete, it must be evaluated to determine whether it was successful or not. The energy storage efficiency, structure stability and system comparisons are the focal points of testing. It should provide relevant data about the capabilities of the device itself, as well as a reference point compared to previous models developed in the MET department.

Rationale

The motivation for this thesis is driven by the relevance of solar energy to humanity's economy and the controversies it brings as well. According to The Intergovernmental Panel on Climate Change (IPCC) humanity's activities have put an enough amount of stress on the environment and are the cause to the dramatic climate change. This special report states, "Climate-related risks to health, livelihoods, food security, water supply, human security, and economic growth are projected to increase with global warming of 1.5°C and increase further with 2°C." (IPCC, 2019) It's important to note that the increase of 2°C is a conservative estimate that would put traumatic amount of stress on the world economy and it can increase much more than. The conclusion to this report addresses that we as a species have approximately 12 years to make dramatic changes to our infrastructure before the changes become irreversible. Just as nuclear warfare was the greatest threat to humanity in the 20th century, it puts not only humanity at the risk of extinction but the entire planet. The second greatest issue we face is trying to avoid this cataclysmic event, while also not allowing out current economic structure to topple.

There is a plethora of ways to combat climate change, mainly though industries that deal with nature, food, and industry, which have the greatest impacts on carbon emissions. This document focuses on renewable energy and more specifically, solar energy. According to the U.S. Energy Information Agency, in 2015 humans used approximately 575 quadrillion Btu of energy (Wirfs-Brock, 2017, Inside Energy). One Btu is the equivalent to lighting a match, and with the current population just short of 8 billion persons; that's enough energy for each person to light 78 million matches each year. There is no doubt these statistics have risen since this analysis was conducted, which adds to the notion that we are facing an unprecedented energy crisis.

The simple fact of not having enough energy creates many other issues such as, higher prices on fuel, food, and services. However, through science and the sheer will power of humanity we have been able to overcome many of the obstacles in our past. These principles have allowed us to conquer the oceans, the sky, and even some of the vast space around us. Many scientist,

engineers, and researchers are working around the clock to develop the technology of the future that may conquer the sun and solve out energy crisis, while also safeguarding our planet.

1.b) Climate Change

Discovery

For years the entire idea of climate change has been a controversial topic. On one hand, it has been a hoax and a rouse to prevent individuals from changing their spending or investing habits. Lobbyist and representatives from major oil, coal, and gas corporations have pushed negative public opinion of the notion as well as laws to maintain their profits. Furthermore, the media coverage coming from various outlets is influenced by economic and sociopolitical agendas that tend to confuse the general public. A study from 2005 concluded that of 32 media reports regarding climate change only 21 were established from valid scientific research that included scientific authors (Phillips M., 2015). This supports the hypothesis that media reports can often cause confusion among the general public. While on the other hand, climate change is monitored by many of the world's leading scientists and researchers to accurately explain this phenomenon. One of the earliest pieces of evidence to support climate change was collected in 1959 at a measuring station located on Mauna Loa volcano in Hawaii. The station monitored carbon dioxide and other emissions in the atmosphere and their readings showed that carbon dioxide was not being fully absorbed into the oceans and was inexorably rising (Urry J., 2015) Continued research by multiple countries and agencies lead to the establishment of the IPCC in 1988, which by 2007, stated human activity was changing the global climate without a doubt.

Consequences

Predictions from the most recent IPCC reports suggest that without significant changes to human infrastructure and behavior, by 2100 we could expect rises in temperature up to 4 degrees Celsius. This change would make life in many areas completely uninhabitable, mainly areas near the equator. This is the worst-case scenario that would worsen many of the current issues our society already face such as, famine, wealth inequality, mass migration, war, and many more. Just within the last hundred years studies have acknowledged that after the industrial revolution the frequency of natural disasters has increased substantially. There are more droughts, more super storms and wildfires. With the evidence collected so far, the severity and frequency of these events are only expected to increase. A collaborative study from Cambridge, University of California, Berkeley, Princeton and other affiliations made this conclusion about the estimated economic damage to the U.S. due to climate change, "The combined value of market and nonmarket damage across analyzed sectors—agriculture, crime, coastal storms, energy, human mortality, and labor—increases quadratically in global mean temperature, costing roughly 1.2% of gross domestic product per +1°C on average. Importantly, risk is distributed unequally across locations, generating a large transfer of value northward and westward that increases economic inequality" (Hisang S., 2017) When considering that the IPCC estimates, this means the U.S. could see a cost of 2.4% - 4.8% of GDP. Based on the U.S. current GDP of 19.39 Trillion dollars, that is a potential cost of 465 billion to 931 billion U.S. dollars. To put that value in perspective, the 2018 U.S. military budget signed by President Trump was just short of 700 billion dollars. This is a matter that should not be considered lightly and luckily the situation has

gained more and more traction over the years prompting advances in combative technology and policy.

Solutions

The fact that we are aware of this issue is our greatest advantage against global climate. Knowing the consequences of climate change have shifted market interest and research that not only help to develop solutions on a large scale but also help to support the economy. Corporations and governments alike have been affected by the changes in climate and will be forced to try and solve the issue. The Paris Agreement is an agreement established in 2016 by United Nations that deals with greenhouse-gas-emissions mitigation, adaptation, and finance. This agreement was signed by numerous countries and requires all parties to put their best efforts to implement policies that help to limit global warming to 2 °C. The Paris climate agreement addresses several of the methods that are vital to achieving this goal. Along with other studies, the most notable methods are carbon-emission reduction and decarbonization systems. Essentially, limit the amount of carbon we put in the atmosphere and/or remove the carbon from the atmosphere and store it.

Generally, when solutions are discussed, carbon-emission reduction is the primary focus. This can be accomplished by transitioning away from fossil fuel use, reconstructing our industries that lead to increase carbon emissions, and developing more efficient renewable energy systems. A 2017 study published by PNAS states, if we avoid increases in fossil fuel emissions for 10 years and then drive them down to 7% of current levels by 2050 and then to zero by 2095. This scenario assumes a 10-year linear increase of Natural Climate Solutions to the cost-effective mitigation levels, and a >66% likelihood of holding warming to below 2°C. To improve the chances to achieve the 2°C goal more methods must be implemented (Griscom B., 2017) Renewable energy is one of the methods that is garnering more and more traction due to its declining costs and zero carbon emission qualities. Following this section, the focus will shift primarily towards solar energy and its relation to the DAST. Solar power currently has the fastest growing industry among renewable energies due to its declining costs, job creation rate, and its use of the most abundant source of energy, the sun.

1.c) Solar Energy & Industry

Overview

To better understand the innerworkings of these systems, we must understand where the energy comes from, how it's collected, and finally how it's used. The sun provides energy to all the natural systems on Earth, from the energy we use to move our bodies to all the weather systems. The sun is essentially a massive nuclear reactor that radiates energy into space, so much that within an hour it provides enough energy to meet the world population's energy demands for an entire year. This energy is harnessed either through solar thermal storage or through photovoltaics (PV) systems, commonly associated with solar panels. Solar thermal storage is generally used for large-scale production of energy while PV systems are small-scale and more feasible for consumers. The DAST uses a PV panel which converts the light from the sun directly into electrical energy using semiconducting materials. When sunlight hits the material, electrons begin to move and create direct current (DC) electricity. DC electricity must be

converted to alternating current (AC) electricity because that is the primary form of electricity used to operate most household appliances and electrical grids.

Technology

The DAST system is an experimental model that is not profit driven. Therefore, it wasn't designed to operate for a specific application. However, the scope of applications for any PV system should be acknowledged to distinguish how the DAST might be applied. The first solar cell was announced by Bell Labs on April 25th, 1954 with a 6% efficiency rating. Since then, there have been numerous advances. PV technology was initially used for satellites, but over the years developments in the technology have allowed its applications to become more diverse. "The main applications are dominated by telecommunications, water pumping, public lighting, BIPV, agriculture, water heating, grain drying, water desalination, space vehicles and satellites" (Sampaio P., 2017) It is very likely that in the future solar applications will expand into the fashion and automotive industry. There are already developments in tiny solar cells that can be embedded in clothing to absorb and store energy, called smart garments. (Chai Z., 2016) A German automotive company, Sono Motors, is already projected to release an electric vehicle in 2019 that is equipped with various solar cells all over the vehicle, so it can charge itself.

While the possibilities for solar cells have a high ceiling of potential, the technology is still developing and is affected by factors out of human control. Solar panels are limited by the climates of the regions they are used in. Also, the cost of the region's electrical grid plays a role in the viability of a photovoltaic system. This is where Maximum Power Point Technologies (MPPT) are most useful. By implementing a MPPT such as the DAST, a consumer can capture more energy. The solar irradiation (sun's power that can be detected) on earth changes in angle and intensity as the Earth rotates throughout the day and varies by season. The MPPT senses the maximum point of irradiance and focuses the panel's alignment with that point to absorb the most sunlight.

There are generally three types of systems that the public is used to seeing: fixed, single-axis, and dual-axis systems. A fixed system is when a PV panel is fixed to one location, such as on the roof of a house. The fixed system is the cheapest method but not the most efficient. The single-axis tracking system is the simplest form of the MPPT. They track the sun by movement along one axis and typically are aligned with the true north meridian. There are various forms of single axis trackers: horizontal, vertical, tilted, and polar aligned. The single axis trackers are generally used on massive scales in solar farms in locations that typically have prime conditions for solar energy production. The dual axis solar tracking system is the most complex MPPT. This type of systems is most useful in areas with limited exposure to sunlight or that have sporadic weather conditions. This can also be necessary in areas where the consumer is not near a reliable energy grid or when one is unavailable. The two general systems are the azimuth-altitude dual axis trackers (AADAT) and the tip-tilt dual axis trackers (TTDAT). The DAST system is an AADAT and is comprised of three major elements: the solar panel, the mechanical system, and the electrical system.

Components

The PV panel used in this iteration is an ARCO M-25, it is considered a classic model by today's standards because its prime production was during the late 1970's. There have been significant advances in this technology since, but this model was among the available resources and was used as the foundation for designing both the mechanical and electrical systems. The mechanical system is a combination of structures, bearings, and links that are meant to support the overall system and operate it as intended. The full lists of the components can be referenced in the aforementioned report, but an overview would show that the mechanical system is divided into two sections, the base and the moving components.

The base was primarily comprised of wood that encased the major electrical components and supported the moving components. A linear actuator controls the altitudinal axis (vertical position), while a stepper motor controls the azimuthal axis (horizontal position), these are considered the drivers. It's important to note that the drivers act as a bridge between both the mechanical and electrical systems. The drivers are provided power and direction by the electrical system. A workflow chart of the electrical system can be referenced in appendix B.5. There was much consideration in the flow of wires throughout the DAST to ensure there is no interference with the moving components, such as a central housing shaft as well as clearance through the base.

Once the whole system is completely assembled it must be programmed to track the sunlight. Four light-dependent resistors (LDR) are used to register photons received on the surface of the solar panel and then adjust the structure to align perpendicularly with the maximum point of solar irradiance. The LDR's are positioned in a way that represent general compass directions. The DAST can be considered a prototype based on the availability of resources used to construct it, but this provides a general idea of standard components that are implemented in a typical MPPT. The coding for the device is constructed by the EET assistant. While the DAST was constructed in this format, it addresses a method that provided a different perspective on these systems. The technology that is currently being developed within the industry will only improve the quality of future iterations

Industry

The developments in this industry are primarily focused on improving the PV with more efficient semi-conductors or better structures. The tracking systems themselves also improve with time as researchers find new ways to track solar irradiation as well as ways to work around climate. For instance, there is a bifacial PV panel with a patent document in 2016 that can absorb energy from both sides and can absorb up to 50% more energy than a standard PV (Scheulov I., 2013). Also, as solar power becomes more popularized and cost effective it will be more generally used on larger scales. There is massive funding for solar farms in space as the amount of solar radiation the surface of the earth receives is only a small fraction of the radiation that is emitted into the vacuum of space. The primary areas that companies have focused their interest are within higher longitudes because these are the areas that benefit most from the use of MPPT. Solar power is expected to be the most abundant source of energy in the future with applications in every major aspect of society. This will create more jobs in this sector. This is mainly influenced by the

continued pressure from grass roots organizations and the ever-changing public perception of solar energy and climate change, as well as the continued price drops in renewable energy.

1.d) Market & Policy

Job Market

A 2014 study published by the British Institute of Energy Economics addresses policy for pro-Renewable Energy (RE) and Energy Efficiency (EE) and provides supporting evidence that suggest as society transition away from carbon-based energy, more jobs will be created. The results of the study state, “positive effect could be of the order of magnitude of 0.5 job/GWh. The average for fossil fuels from these figures is about 0.15 jobs/GWh (coal 0.15, gas 0.12, CCS 0.18), the average across all RE is 0.65 jobs/GWh, and the average across all RE and EE is 0.80 jobs/GWh.” (Blyth W., 2014) The results of this data indicate how many jobs are created in relation to the gigawatt hours that are generated from the specific energy sector. The study uses a literary review of over 40 scholarly articles that focus on employment impact and low carbon economy. As more research is conducted, there will be more evidence to support the use of an integral large-scale RE and EE system. As more jobs arise there will continue to be a push for more solar energy projects among the public and corporations.

The solar industry will account for majority of the jobs being created for renewable energy. This is not only due to the fact that the idea of solar energy has become a more mainstream concept but that the prices for installation continue to drop. Based on annual report from Lawrence Berkeley National Laboratory (LBNL) the price for PV installation declined by 6% from 2016 to 2017 and then 11% from 2017 to 2018. The report is compiled from an analysis of roughly 1.3 million PV system within the U.S. Their report suggests that this trend is expecting to continue for the foreseeable future. When thinking of the long-term impacts of solar energy it is clear that most experts expect the largest changes to come along with government and policy reform. “The U.S. Department of Energy’s Solar Energy Technologies Office, for example, has sought to reduce costs to \$1.50/W for residential systems and \$1.25/W for commercial systems by 2020, and by an additional 50% by 2030” (Barbose G., 2018) It is expected that due to climate change many national and international governments are receiving pressure to continue to reduce the price of solar installation and other renewable energy methods.

Policy Trends

As mentioned before, the Paris Climate Agreement is a crucial document that addresses the changes that need to occur to prevent further harm to the environment and our world economy. Now more than ever, it is important that changes to the energy industry must be made to ensure there is a safer, cleaner, and more prosperous world for future generations. Therefore, many of the world’s largest organizations and agencies that are focusing their efforts solve climate change are taking notice and trying to implement more progressive policies. The United Nations has established a list of 17 sustainable development goals that are intended to be achieved by 2030. While, it may not be realistic to accomplish all the intended goals by 2030, the list provided a beacon of accomplishment for countries to strive for. Goals 7: Clean and Affordable Energy and Goal 13: Climate Action are the most relevant to this thesis. Both goals address the importance and necessity of renewable energy, and mention solar energy specifically, as a cornerstone of our

society. The significance of these goals and Goal 13 specifically is that it intended to be implemented beyond the major developed countries. It states, “mobilizing jointly \$100 billion annually by 2020 from all sources to address the needs of developing countries in the context of meaningful mitigation actions and transparency on implementation and fully operationalize the Green Climate Fund” (U.N., 2019). Generating \$100 billion dollars annually to improve the infrastructures of less developed countries should provide much assistance to their economies and the fight against climate change.

While in the United States, the U.S. Department of Energy and the Environmental Protection Agency (EPA) are the driving forces behind continuing the progress in the renewable energy sector. The EPA states that, “the top eight states ranked by the capacity of their installed solar power include states in the southwest and northeast (CA, NJ, AZ, MA, NY, NV, TX, PA)) represent 99.5 percent of all solar PV installations”. However more states in the west and southwest would benefit from the use of PV systems. This means there is a gap in nationwide energy generation efficiency. Luckily, the EPA itself established numerous programs and implements policies that are meant to support more investments towards PV installations:

- **Renewable Portfolio Standards (RPS):** Require electric utilities providers to provide a percentage or set amount of customer electricity with eligible renewable resources.
- **Net Metering:** Enables residential or commercial customers who generate their own renewable electricity via solar photovoltaic panels or other sources to receive compensation for the electricity they generate.
- **Solar Energy Technologies Program:** Focuses on accelerating competitiveness within the market through cost reductions and supporting increased solar deployment.
- **Solar Power Purchase Agreement (SPPA):** A financial arrangement where third-party developers own, operate, and maintain a photovoltaic (PV) system then a customer hosts the system their property and purchases the system's electricity for a set period of time.

There are many strategies in place to propel this growing market to new highs and it is clear that within the decades to follow there will be more progressive policies to come.

Methods

The approach to analyze the DAST is focused on its performance in comparison to similar systems of equal or lesser quality as well as its viability within the market based on the literature review conducted. This section analyzes the data collected during the testing phase and the data of similar projects in order to quantify the device's success. Along with the quantitative analysis, the project's fit within the current market is addressed based on the literature review conducted in the previous section. After having completed both analyses, a hypothesis of potential changes to the DAST can be established to improve its viability and marketability. Data from the testing phase and further information are provided in the Appendix of the "Dual Axis Solar Tracker" document.

2.a) Quantitative Analysis

Testing & Results

Once the device was fully assembled there were a total of three tests conducted in order to assess its functionality. The first two tests were preliminary tests of the actuator and stepper motor. These tests focused on ensuring that both drivers would be programmable and to test their full range of motion within the system. An in-depth overview of the procedures for these tests as well as the results can be referenced in Appendix I. The actuator worked as intended with a max angle of declination of 55 degrees and a minimum of 38 degrees. Minor adjustments were made to the platform to reduce the interference when the actuator was in motion. Initially, the motor was not functionally due to a miscalculation of torque requirements. The motor was sized at 59 N-cm based on calculations from the Winter quarter. However, the radial load was much larger than anticipated and the new torque required to move the horizontal axis was 5.7N-m. This issue was corrected by applying a planetary gear system to the motor with a 100:1 ratio. Lastly, the third test was the most critical of the tests because it focused on the power efficiency of the system. In short, the system was set up outside of the Hogue building for a period of 5 hours collecting solar energy along with a fixed PV. The voltage and amps were recorded in 30 min increments from 10:00 am to 3:00 pm. This data was used to calculate the power of both systems. During the third test the motor was not functional and therefore the system tracked the sun manually, meaning at the 30 min intervals the horizontal was manually repositioned using data from www.timeanddate.com and was calibrated for precision using a digital compass. Future tests will be conducted with the new working motor.

Once the data was collected and analyzed it showed that the device yielded successful results. The design requirements established for the project were to absorb 25% more energy than a fixed PV system or approximately 100 watts. The fixed solar panel on average absorbed 73.8W while the DAST system absorbed 102.5W. This meant that the DAST absorbed 38.9% more energy than the fixed system and on average 2.5W more than anticipated. The max power recorded by the DASTS was 111.2W while the fixed system had a max power of 81W. All the raw data for the tests can be referenced in Appendix G. The data also presented a few interesting trends and discrepancies. The expected trend for the DAST system during testing was that it would maintain more consistent and flatlined pattern, however, the system had more of a parabolic trend. The information could be negligible due to the fact that the system was being repositioned manually. Also, the gap between the first and last data point of the DAST only differed by 7W as opposed to the 20W gap of the fixed system. The fixed system was expected to have a parabolic trend that had a max power

rating in correlation with the peak solar hour (1:00pm). However, the fixed system's data was much closer to a linear trend as the power rating continued to rise throughout the test. The reason for this difference is most likely due to the fact that the fixed system did not have a voltage regulator to monitor the distribution of power once the battery that it was connected to was full. Meaning, the energy was trapped inside of the solar cells. A hand check of both panels after the tests showed that the fixed system had significantly more residual heat from it. Regardless of the inconsistencies the data still provided useful results.

Tracking System Comparison

Two other dual-axis solar tracking systems are analyzed in this process to address the project's success among similar devices. The first is a solar tracker also designed and constructed in the CWU MET program during the 2017-2018 school year by Haoyu Liu. This system is an ideal candidate for comparison because it uses the same PV panel as the DAST as well as uses similar testing methods. The second tracking system was design and constructed at the Worcester Polytechnic Institute by Adrian Catarius and Mario Christiner. This system is also a valuable source for comparison because it was developed by different methods and uses newer components than DAST system.

The solar tracker designed by Haoyu Liu was meant to provide a 20% increase of energy comparison to a fixed system. The design for this device was much smaller in size because it does not include a base for the electrical system. Also, the PV panel is mounted on a central support beam. The mechanism for changing the position of the PV is on top of this beam. The biggest difference in this system in comparison to the DAST is that it uses two motors. The qualities of this system allow it to weigh less and make it easier to program because of the consistency in drivers. The data presented in the "Solar Tracker" report show similar results to that of the DAST. The power of their system and their fixed system were 107.2W and 82.3W, respectively. This provided an increase of 23% per hour. However, these values were the max power ratings. The DAST system provided a 15% increase in power over this system as well as had more consistency throughout the testing. The biggest reason for the advantages of the DAST of this system is that it is able to track the sun with a less than 3% tolerance (deviation from maximum power) while this system has a tolerance of 5%. Lastly, the total cost of this design was \$343 while the total cost of the DAST was \$246.41. The \$96.59 difference and improved efficiency makes the DAST the more attractive option for potential consumers.

While the dual axis solar tracker from the WPI undergraduates differs widely from the design of the DAST, their results provide valuable feedback than can be used in the assessment of this device. This system uses an array of solar panels with sensors to track the sunlight. It also uses 2 dc motors and worm gears to generate its motion. The DAST uses a much larger solar panel which makes the actual comparison of data hard to compare. The max values this system records are 101mV and 0.62 A, meaning it generates significantly less energy. However, the final results of their findings show that the system generates roughly 48.9% more energy than an immobilized PV. This important to note because while they generate less energy they are using much more modern panels while using a method that generates roughly 10% more energy on average than the DAST. The final prototype for this system came to a total cost of \$333.99, which is \$87.58 more than the DAST system. The design for this project can be scaled up to suit a larger panel or array

of panels. While it would certainly cost more, if the same increase of energy can be maintained it would be a much more viable option on the market.

2.b) Qualitative Analysis

Viability and Marketability

It is important to acknowledge that the DAST is at the prototype level. It has been developed on a limited time frame and with limited resources. The ARCO M-25 solar panel used for this system was the basis of the design. This is problematic for future iterations as the ARCO company was bought out in 1990. This information was discovered several months into the project's development and because of that there were no official specifications of this model available. In today's market a typical solar panel is about 3' by 5' and produces 200W-400W of energy. Using the current PV panel, the system can only produce half the power of a lower-end typical panel. This means this device has two options to become a viable option on the market. It can either be used as a novelty product for beginners and experimenters or it can be modified and scaled to incorporate a more modern PV panel.

The device uses roughly 3.13 sq. ft. of space and weighs 66.4 lbs. Also considering that a more available solar panel with similar constraints will be needed the price of the final product will most likely be around the \$300 price range. Considering all these factors, this device is most likely a promising candidate as a personal charging device for small systems. In its current state, the DAST can be used to power a small gardening system, charge multiple phones or electronic devices at once, or simply store energy in back-up batteries. With the increased interest in solar energy, more jobs will arise to create systems such as this one for the general public. As stated in the previous section the majority of the market is focused on the commercial sector with larger systems being the most purchased of products. This is because of the incentives from different programs and policies to generate energy through renewable energy and the benefits of being a third-party supplier.

Improvements

In an effort to better represent this product on the market, there are some things that most certainly need to be addressed. A Regony PV panel was sourced from Amazon as an alternative for the current ARCO M-25 PV panel. This new panel will cost \$59.99 with free shipping, bringing the total cost of the device to \$306.40. The Regony monocrystalline PV panel is an ideal upgrade as its specifications state it has a 30W power output which is 5W more than the current models' unofficial specifications. Also, the current dimensions of the device are 22.25" x 12.75" x 1.875". The Regony model has dimensions of 23.6" x 13.4" x 1.0". This means the only component that would need to be modified would be the panel frame and it would only be minor adjustments. To better improve the device's use of space it may be beneficial to redesign the base of the system. Both of the devices previously analyzed were able to establish smaller volumes based on their ability to compact the systems. The DAST has a lot of open space within the base that can be used for applications but because there are no specific intentions for it, that space goes unutilized. As stated before a small agricultural system for plant or food watering may be a good idea. Not only would it provide purpose for this space but also provide an appeal to a particular niche market. It appeals to not only technology and solar enthusiasts but also to gardeners and plant lovers.

2.c) Conclusion

Summary

There is reasonable evidence from the literature reviews conducted that climate change is a real issue that we as society face and that solar energy will be a vital component of the solution. The founding of the IPCC in 1988 mark a major milestone in the fight against climate change. In the years since, this panel has established numerous reports that have helped better understand the damage we as a species has inflicted onto our environment, as well as addresses potential solutions to right our wrongs. The world will continue to be plagued by the consequences of climate change in the years to come regardless of the changes we make in our behavior.

However, their reports confirm that we have approximately 12 years to make necessary changes to our way of life before the worst aftermath of climate change is inevitable. If we don't keep our global warming below the 2-degree threshold temperatures with rise to fatal levels in highly populated areas, superstorms of unprecedented proportions will become very frequent, water will become scarcer, and much more.

Luckily, many potential solutions to this problem have been discovered. Renewable energy and solar energy specifically will become an essential aspect of our society. The first solar cell was invented in 1954 and since the world has taken notice of the enough potential that this technology has to offer the world and our economy. The first cell began with a mere 6% efficiency and today they can reach up to 25% efficiency. Beyond that, there have been a multitude of tracking systems implementing MPPT to improve the amount of energy absorbed by the sun. While the market currently is focused on the commercial farming of solar energy it is forever expanding to all possible consumers. Research in renewable energy and solar energy show that there will continue to be an increase in job growth in this sector as well as declining prices of installation and product development. Along with more progressive programs and policies for renewable energy and energy efficiency, this industry will continue to play an important role in combating climate change as well as fueling the world economy.

Impact

The DAST project presents both a viable business opportunity as well as an outlet to promote the issue of climate change. After analyzing the similar dual-axis tracking systems it is evident that the DAST is a high performing device given the limited resources provided. While it absorbs 38.9% more energy than a fixed system, there is still room for improvement. Taking inspiration from both other devices, potentially redesigning the DAST to hold an array of panels with on a central support beam would theoretically yield 10% more energy as well as reduce the weight of the total system. However, the current model with a simple PV panel replacement should provide a promising product that can be marketed as a personal charging station that can be manufactured for no more than \$307. The DAST can address climate change on a local level while having a global impact, not only on the economy but on our world. With enough support for devices like this, we may be able to change the world for the better.

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